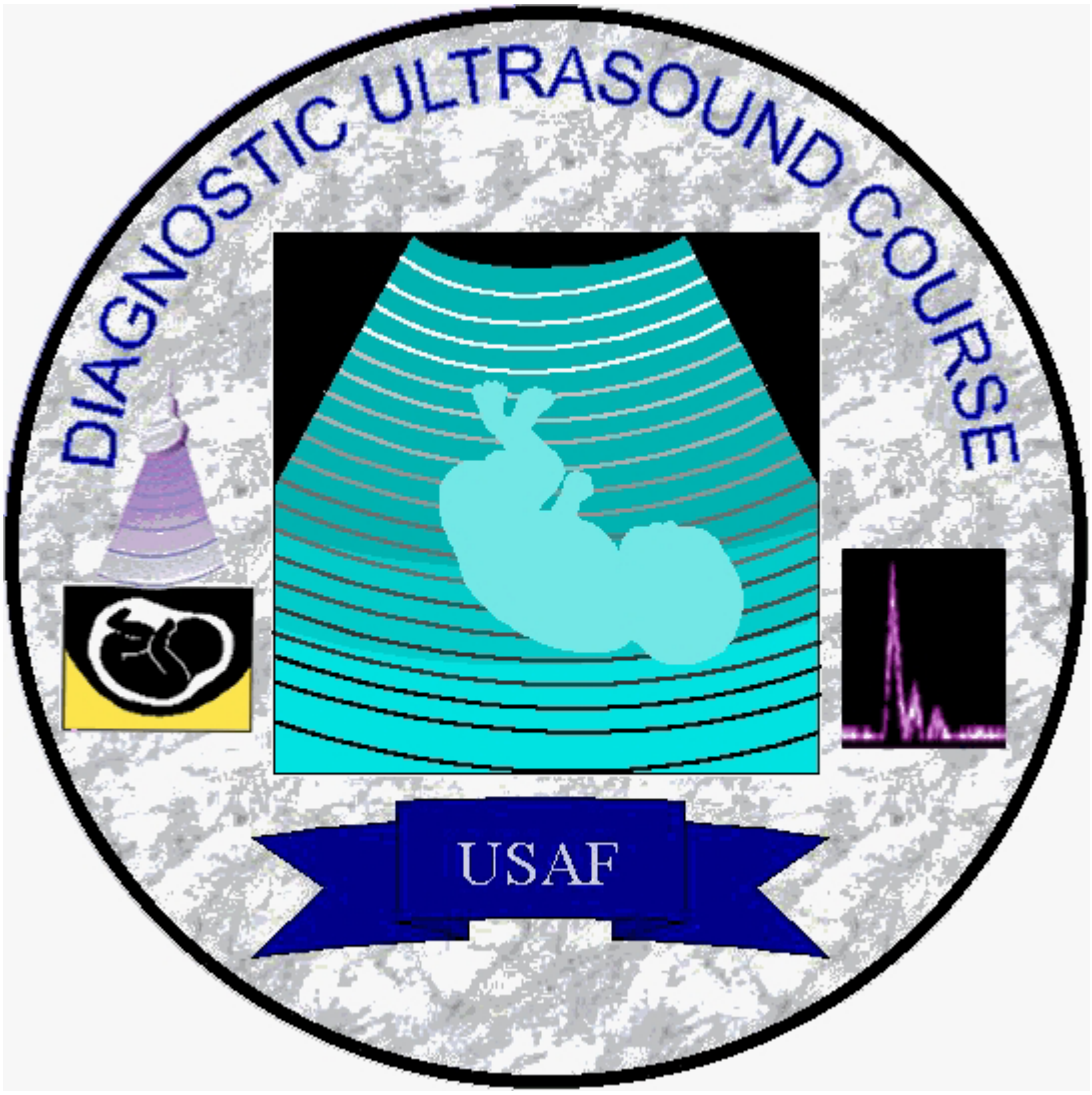
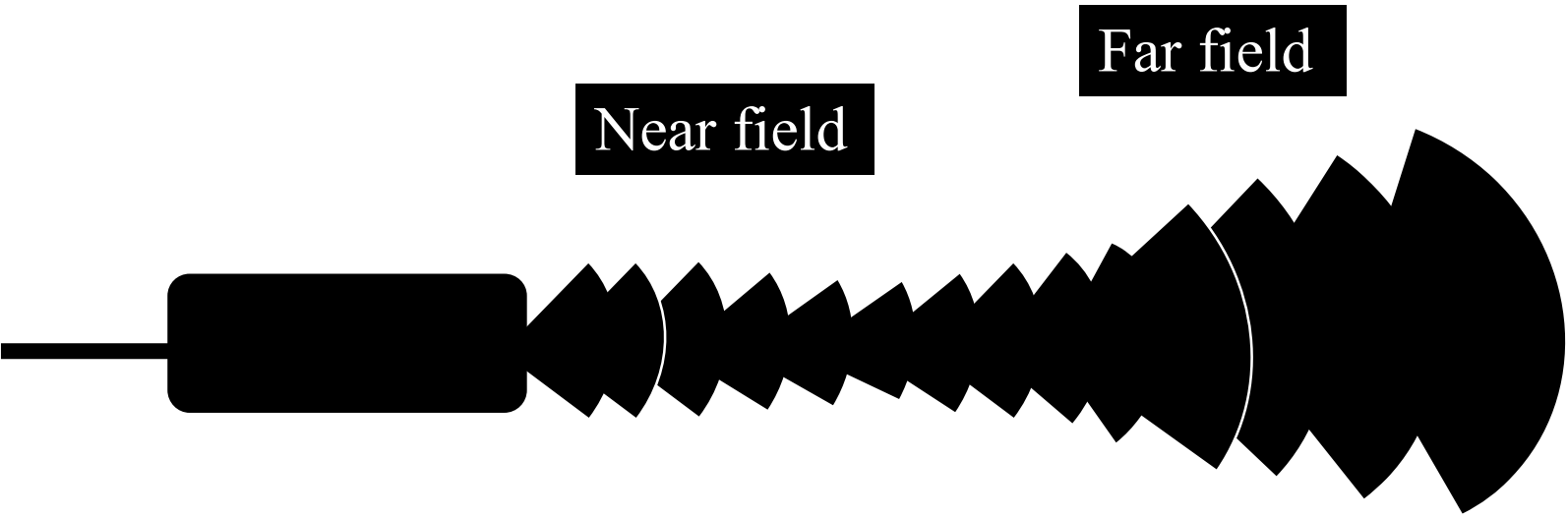
Diagnostic Ultrasound Study Guide
B-Shred 4R051/4R071B

March 2003



Pulsed and Continuous Wave Basics

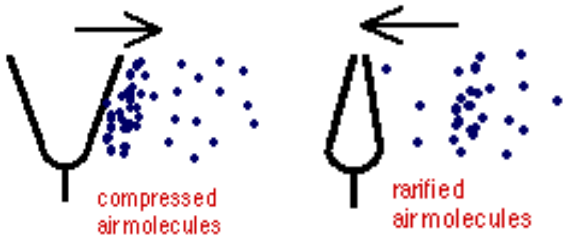


Pulsed and Continuous Wave Basics

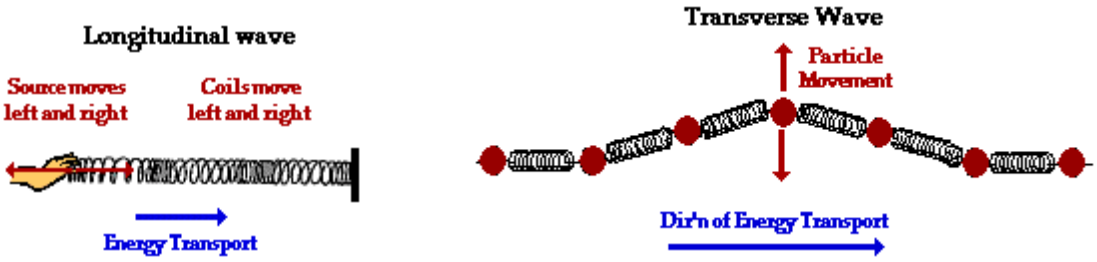
What is Sound?
Sound is a mechanical wave form energy transmitted by vibrations in a material medium. *Mechanical* means it requires physical movement of molecules to travel; unlike x-rays, which are electromagnetic energy. Sound requires a material medium through which to travel. Sound does not exist in a vacuum.

Sound is created when an object (such as a tuning fork or vocal cords) begins to vibrate causing the molecules adjacent to the object to vibrate also. These molecules, in turn, cause other molecules to vibrate, and on and on. In this manner, the sound travels outward in a wave from the object similar to ripples in a pond.

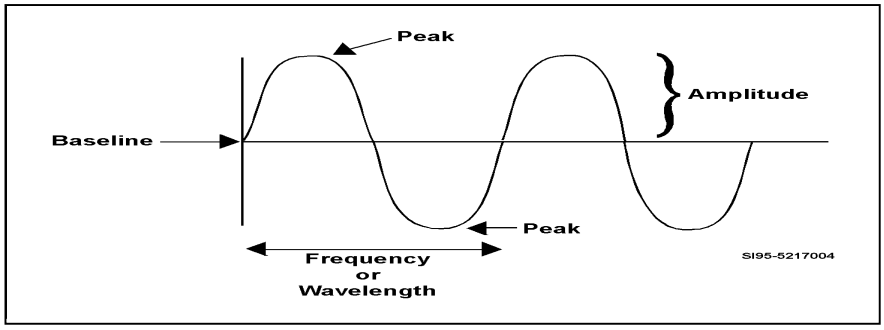
The sound wave consists of areas of molecular **compression** (increased pressure) as the molecules push outward from the source and areas of molecular **rarefaction** (decreased pressure) as the molecules draw back toward the source.



Sound travels in **longitudinal waves**, like a piston vibrating back and forth. Other types of mechanical waves travel transversely, vibrating perpendicular to the direction of travel. Transverse waves don't travel well through soft tissue. Therefore, longitudinal waves are the only ones we are concerned with in diagnostic ultrasound.



Physical Properties of Sound (Continuous Wave)
We use a sine wave to illustrate the various properties of a sound wave because it is a convenient visual tool. However, sound doesn't actually travel up and down, but rather back and forth.



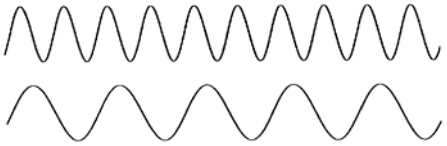
The Sine Wave

Frequency
The number of cycles per second, measured in **Hertz** (Hz). One cycle is equal to one area of compression and one area of rarefaction together.

Common frequency units:
1 cycle/second=1 Hertz (Hz)
1,000 cycles/second=1 kilohertz (kHz)
1,000,000 cycles/second=1 megahertz (MHz

High Frequency

Low Frequency



Sound classifications by frequency
Ultrasound is sound energy with a frequency above the range of human hearing, or above 20 kHz.*

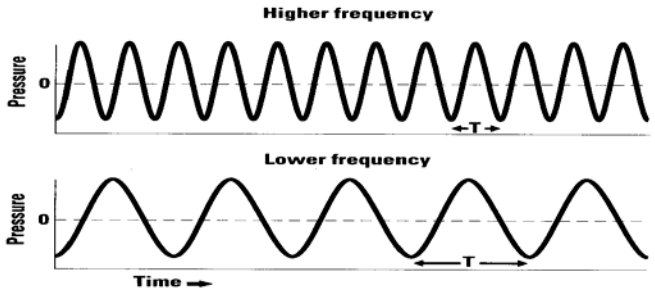
Audible sound occurs within the range of human hearing, or from 20 to 20,000 Hz.

Infrasound is below the range of human hearing, or below 20 Hz.

- ***NOTE***: Diagnostic ultrasound frequency ranges from 1 MHz to 20 MHz

Frequency is a property of its source. In medical ultrasound, in order to change frequency, we almost always must change transducers (except in the case of special multi-frequency transducers)

Period
The length of time it takes to complete a single cycle.



Period is also determined by the sound source, and is, in fact, inversely related to frequency. That is, as frequency increases, period decreases; as frequency decreases, period increases.

The following formula relates period (T) and frequency (f):

$$T = \frac{1}{f} \quad or, \, equivalently \quad f = \frac{1}{T}$$

Example—What is the period of a 1 MHz sound wave?

T = 1/f = 1/1 MHz = 0.000001 seconds = 1 μsec

Wavelength
The length of one complete cycle is called the wavelength.

Wavelength is determined by both the sound source and the medium. It cannot be adjusted by the sonographer except by changing transducers.

Wavelength is equal to the speed of the sound beam divided by the frequency (λ=c/f). For medical imaging, the speed of sound is nearly constant. Therefore, wavelength is determined almost solely by adjusting frequency. Increasing frequency decreases wavelength; decreasing frequency increases wavelength.

Example—What is the wavelength of a 1 MHz ultrasound beam traveling through soft tissue?

$$\lambda = \frac{c}{f} = \frac{1540 \, m/s}{1{,}000{,}000 \, cycles/s} = 0.00154 \, m = 1.54 \, mm$$

Image detail is directly affected by wavelength. The shorter the wavelength (higher frequency), the better longitudinal resolution. The longer the wavelength, (lower frequency), the poorer the longitudinal resolution.

Sound Speed
The speed at which sound moves through a medium is the sound speed. The speed of sound is generally measured in meters/second or millimeters/microsecond.

Sound Speed is determined solely by the medium through which it travels. Specifically, the speed of sound is determined by the density and stiffness of the medium. All sound, regardless of frequency, travels at the same speed in the same medium.

Speed is inversely proportional to density.
Speed is directly proportional to stiffness. (Stiffness refers to a material's ability to maintain its shape.)

The average speed of sound in human soft tissue is 1,540 m/sec or **1.54 mm/μsec**. *This is a very important number–remember it!*

Other propagation speeds are:

TISSUE	SPEED
Air	30 m/s
Water	1,480 m/s
Liver	1,555 m/s
Kidney	1,565 m/s
Brain	1,520 m/s
Muscle	1,600 m/s
Bone	4,080 m/s

Amplitude
Describes the magnitude of a sound wave. Amplitude is represented by the height of the curves of the sine wave. In the range of audible sound amplitude relates to volume, but in terms of ultrasound it most often refers to pressure. In this sense it may be *called* ***pressure amplitude*****, or just** ***amplitude***.

Amplitude can be expressed in many different units depending on the specific acoustic variable being measured. However, for our purposes, it is often expressed in **decibels (dB)**. The decibel scale is a logarithmic function used to compare amplitudes with other amplitudes. It has no meaning in and of itself; it is only a comparison of one sound wave with another, or of the same sound wave a different times.

Amplitude is initially determined by the sound source and can be adjusted by the sonographer. Amplitude decreases as sound travels through the body due to attenuation of the sound beam.

Power- refers to the strength of the sound wave. It is the rate at which energy is transferred from the sound beam and is measured in watts.

Power is initially determined by the sound source and can be adjusted by the sonographer. Like amplitude, power decreases as the sound wave travels through the body.

Power is directly proportional to the square of the pressure amplitude. As amplitude increases, power increases; as amplitude decreases, power decreases.

Intensity- refers to the concentration of energy in a sound beam. *Intensity equals the power of a beam divided by its cross-sectional area.* Therefore it is measured in **watts per square centimeter (W/cm^2)**

Intensity is proportional to power. Intensity and power are both proportional to the square of the pressure amplitude.

Intensity is determined initially by the sound source and can be adjusted by the sonographer.
Intensity is an important factor in determining biological effects of ultrasound. Typical diagnostic ultrasound intensities range from **0.01 mW/cm^2 to 100 W/cm^2**.

Intensity is an important factor in determining the potential biological effects of a sound beam. Intensity should be minimized for each exam–especially obstetrical exams.

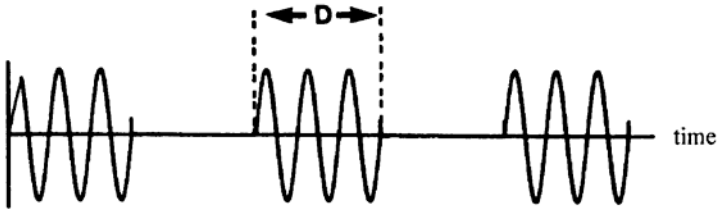
Pulsed Wave Parameters

Most diagnostic ultrasound applications do not use a long continuous wave of sound to gather data for images. Rather, the ultrasound machine sends out a short pulse of sound and then listens for returning echoes before sending out another pulse. All of the characteristics of a sound beam that we have discussed so far still apply to pulsed sound waves, but pulsed waves have a few other characteristics that are important to your understanding of how an ultrasound image is produced.

Pulse Duration is the length of time from the beginning to the end of the actual sound burst usually measured in microseconds.

The pulse duration is the product of the period times the number of cycles in the pulse.

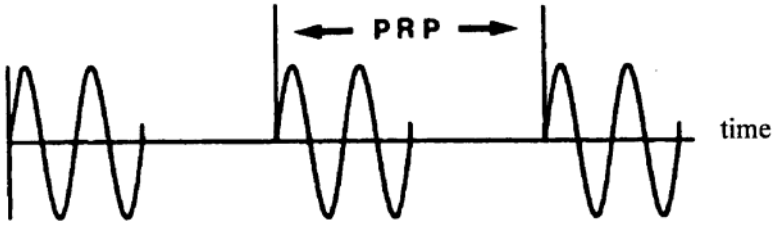
Pulse duration is determined by the ultrasound system (transducer) and cannot be adjusted by the sonographer. In diagnostic ultrasound, **pulse duration ranges from 0.5 to 3 μsec.**



Pulse Repetition Period (PRP) is the time from the start of one pulse to the start of another pulse. It is the sum of the pulse duration and the "dead time" in-between pulses.

PRP can be adjusted by the sonographer by changing the imaging depth. A greater imaging depth requires longer "dead" time to listen for returning echoes.

For diagnostic ultrasound, **PRP ranges from 100 μsec to 1 msec (0.0001 to 0.001 sec)**



Pulse Repetition Frequency (PRF) is the number of pulses that occur per second.

PRF can be altered in the same manner as PRP: by adjusting the imaging depth. As depth increases, PRF decreases. As depth decreases, PRF increases.

PRP and PRF are reciprocals of each other: PRP = 1/PRF and PRF = 1/PRP

↑ Imaging depth = ↑PRP = ↓ PRF = slower frame rates

Duty Factor - The percentage or fraction of time that the ultrasound machine is sending out sound. Duty factor is given as a unitless number from 0.0 to 1.0 or as a percentage.

Duty Factor = Pulse Duration ÷ Pulse Repetition Period

Duty factor can be adjusted by changing imaging depth. In diagnostic ultrasound, duty factor ranges from 0.001 to 0.01 (0.1 to 1%). In other words, an ultrasound machine spends very little time sending out pulses and a lot of time listening for echoes.

Spatial Pulse Length (SPL) The length of a single pulse of sound, measured in millimeters for diagnostic ultrasound.

SPL= λ• # cycles per pulse

SPL is determined by the wavelength and the number of cycles in a pulse, which are both characteristics of the transducer. Therefore, to change SPL you must change transducers.

SPL is a very important factor in determining longitudinal (axial) resolution. **SPL ranges from 0.1 mm to 1 mm in diagnostic ultrasound.**

Interactions of Sound and Propagating Media

The Pulse-Echo Principle

How we use sound to create an image.
Q: If you are standing on one side of the Grand Canyon armed only with a stopwatch and the knowledge that sound travels approximately 330 m/s, could you calculate the width of the canyon?
A: The answer to this question is "yes" and therein lies the key to the pulse-echo principle.

An ultrasound machine is able to produce images of the body by sending a pulse of sound into the body and then listening for the returning echoes. By measuring the strength of

the returning echoes along with the length of time it takes for the echoes to return, the machine is able to derive information about structures in the path of the sound beam. It uses this information to produce an image.

Reflection and Transmission at Interfaces

When sound traveling through a medium encounters the surface of an object with different physical properties than the medium, part of the sound "bounces" off the surface. Before we discuss why this happens, we need to define a few terms.
- The surface that causes the beam to "bounce back" is called an *interface*.
- The beam that encounters the interface is called the *incident beam*.
- The portion of the beam that bounces off is called the *reflected beam*.
- The portion of the beam that continues through the interface along its original path is called the *transmitted beam*.

Acoustic impedance (Z)—We will define acoustic impedance as the degree to which a medium resists the transmission of sound.

Acoustic impedance (Z) is equal to the density of the medium (p) times the speed of sound in the medium (c):
$Z = pc$

Acoustic impedance is measured in kilograms per square meter per second ($kg/m^2/s$). It may also be expressed in *rayls*. One rayl equals 1 $kg/m^2/s$.

Acoustic impedance of selected tissues:

Tissue	Impedance
Air	0.0004×10^6
Lung	0.18×10^6
Fat	1.34×10^6
Liver	1.65×10^6
Kidney	1.63×10^6
Muscle	1.71×10^6
Bone (skull)	7.8×10^6

Reflection

Perpendicular Incidence

An interface is formed when two materials with different acoustic impedance values lie adjacent to one another. If a sound beam encounters a large, smooth interface perpendicular to its direction of travel, a portion of the beam will be reflected back towards its source. When this happens, the reflection is called an *echo*. The large smooth interface is called a *specular reflector*.

The percentage of the beam that is reflected is determined by the acoustic impedance mismatch between the two structures. This mismatch can be quantified by a number called the amplitude reflection coefficient (R).

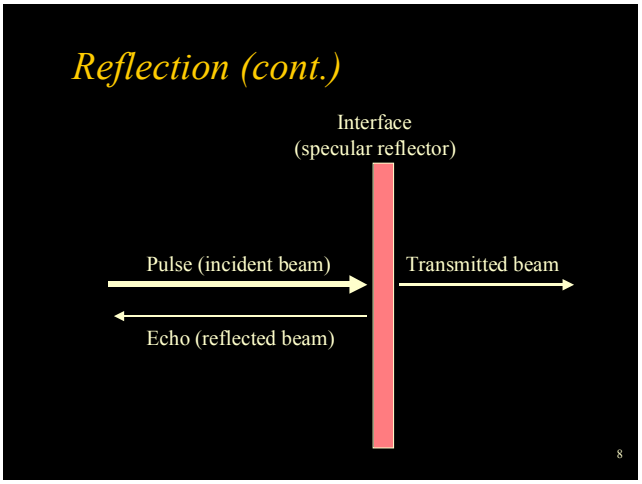
$$\mathbf{R = (Z_2 - Z_1) \div (Z_2 + Z_1)}$$

Where Z_2 is the impedance on the far side of the interface and Z_1 is the impedance on the near side.

Amplitude reflection coefficient for selected interfaces (percentage):

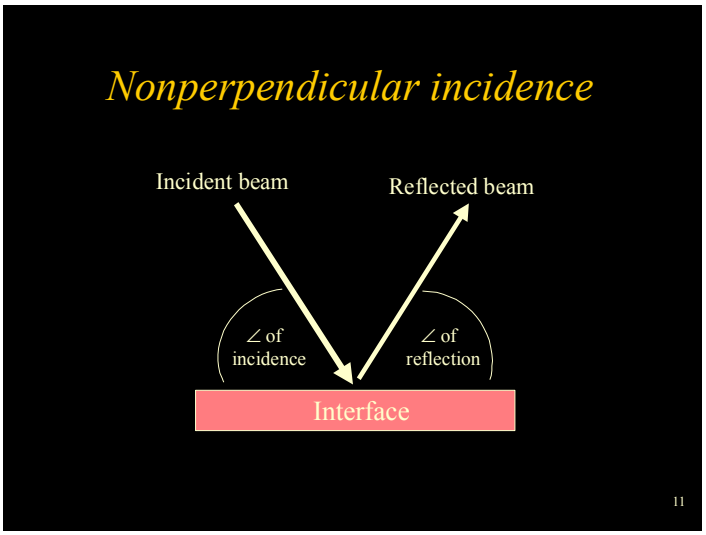
Interface	Coefficient
Kidney-liver	0.006 (.6%)
Liver-muscle	0.018 (1.8%)
Fat-liver	0.10 (10%)
Muscle-bone	0.64 (64%)
Air-muscle	0.99 (99%)

The mismatch between various soft tissues is low, making them ideal for ultrasound imaging. However, the mismatch between soft tissue and bone and between soft tissue and air is very large, making it difficult to image through bone and impossible to image through air. (Hence the need for a coupling gel.)



Non-perpendicular sound beam incidence.

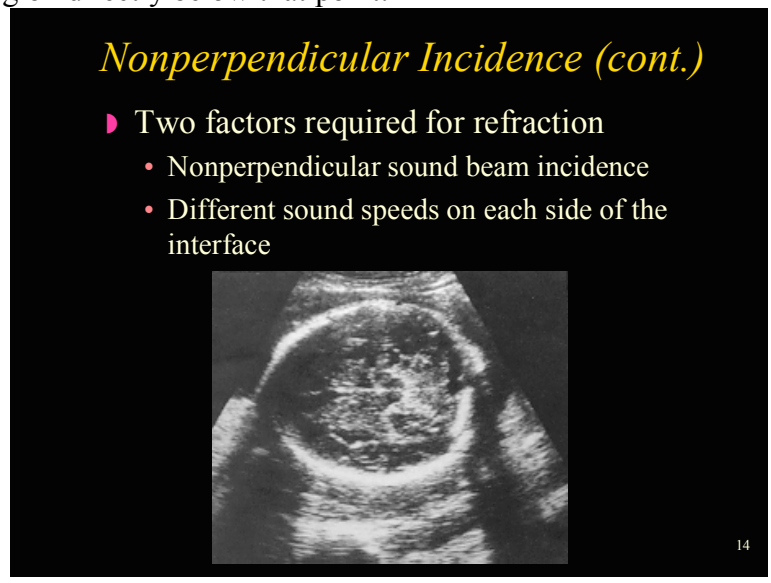
When sound encounters a specular interface that is not perpendicular to the sound beam the reflected beam does not travel back towards its source. Instead it travels off at an angle equal to the angle of incidence. If this angle is more than a few degrees from perpendicular, the reflected beam will miss the transducer and no information will be received to help form the image.



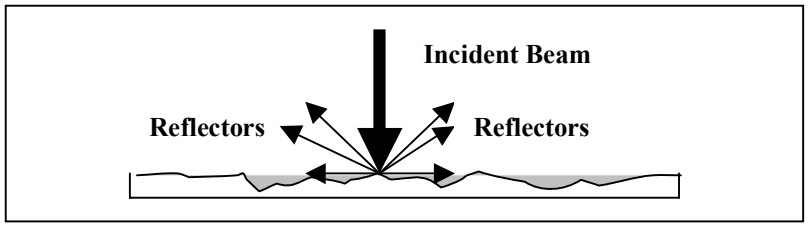
A second factor that arises from nonperpendicular interfaces is ***refraction***. Refraction is a bending, or change in direction, of the transmitted sound beam.

In order for refraction to occur, not only must the interface be nonperpendicular, but also the speed of sound must be different on each side of the interface.

An example of refraction in a fetal skull.
Notice how the sound is bent by the nonperpendicular calvarium wall causing an apparent displacement of the posterior calvarium and a shadow because of the lack of sound in the region directly below that point.



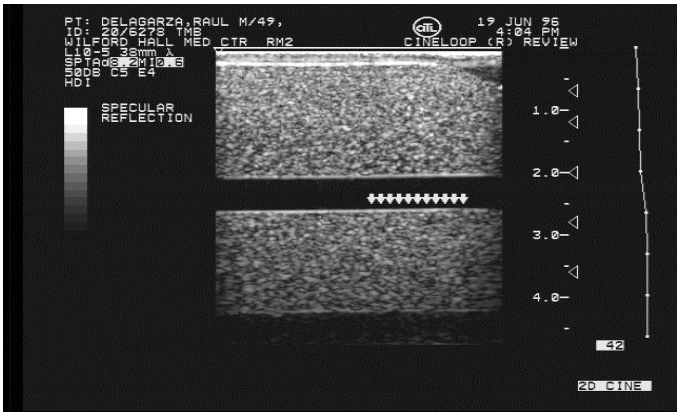
Diffuse Reflection (scattering)—When a sound beam encounters a very small interface (smaller in dimension than one wavelength) or an irregularly shaped interface, sound is reflected diffusely (in multiple directions). This is called a *nonspecular or diffuse reflector*.



Because the sound is reflected in multiple directions, or *scattered*, a portion of the reflected beam always travels back towards the transducer. Although these echoes are weaker, they are not as sensitive to the orientation of the reflector.

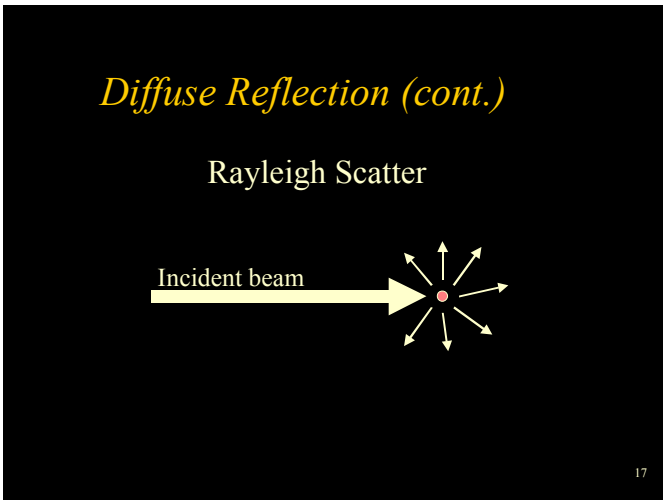
Scattering from diffuse reflectors is what gives an object its characteristic sonographic appearance (echogenicity). For instance:

An object, such as the liver, containing many small diffuse reflectors will have a gray sonographic appearance.



A fluid-filled object, such as the bladder, contains no internal interfaces and appears black sonographically.

Rayleigh scattering is a special type of scattering involving reflectors that are much smaller than one wavelength. For instance, when an ultrasound beam interacts with red blood cells, the beam is reflected in all directions. We rely heavily on Rayleigh scattering while performing Doppler studies.



Raleigh Scatter

Decibel (dB) Notation

Decibel notation is a means of comparing ultrasound signal intensities. It is not a discreet measurement such as pounds or inches, but a means of measuring the difference between two signal levels.

The dB formula. There are two formulas that we use to calculate relative signal levels in decibels. One formula is used when you are comparing amplitudes; the other is used for comparing intensities.

Relative amplitude level:
$dB = 20 \log (A_2/A_1)$
Relative intensity level:
$dB = 10 \log (I_2/I_1)$
It doesn't matter which formula you use to calculate decibels. You will get the same result whether you use amplitude or intensity to perform the calculation because intensity is proportional to the amplitude squared. In other words:

Since $(I_2/I_1) = (A_2/A_1)^2$,

$10 \log (I_2/I_1) = 10 \log (A_2/A_1)^2$ (by substitution)

and $10 \log (A_2/A_1)^2 = 20 \log (A_2/A_1)$ (property of logs)

Logarithms.
A logarithm is a mathematical function that is the inverse of an exponential function. It can be used to represent a large range of numbers on a small scale. For instance, using common logarithms, we can represent all the numbers from one to 10 billion on a scale of zero to ten.

The following list should help you understand logarithms better by comparing them to exponents.

Exponential Form	Logarithmic Form
$10^0 = 1$	$\log 1 = 0$
$10^1 = 10$	$\log 10 = 1$
$10^2 = 100$	$\log 100 = 2$
$10^3 = 1{,}000$	$\log 1{,}000 = 3$
$10^4 = 10{,}000$	$\log 10{,}000 = 4$
$10^5 = 100{,}000$	$\log 100{,}000 = 5$
$10^6 = 1{,}000{,}000$	$\log 1{,}000{,}000 = 6$

You should see from the list that the log of a number is actually the exponent that will cause ten to equal the number.

Relating this to our dB formulas, we want to take the log of the ratio of the second amplitude (or intensity) to the first. This ratio will be a number. We can plug this number into a calculator and hit the <log> button to get the log of this number. Multiply the log by 20 (or 10) to arrive at the decibel difference between the two signals.

The 3-dB rule.
An increase of 3 dB represents a doubling of intensity. A decrease of 3 dB represents a halving of intensity.

Attenuation of Ultrasound Beams

Attenuation is the decrease in amplitude and intensity of a sound wave as it travels away from its source. There are two causes for attenuation within the body: (1) reflection and scattering, and (2) absorption.
As you now know, reflection and scattering cause a portion of the sound beam to be diverted in another direction leaving less of the primary beam to continue on in the original direction.

Absorption occurs as friction from the vibrating molecules converts the sound energy into heat. At the power levels used in diagnostic ultrasound, the heat produced is minimal, but at higher settings, ultrasound is used as heat therapy for certain types of injuries deep in the body.

Attenuation coefficient is a number that represents the amount of attenuation that occurs per centimeter of tissue measured in decibels per centimeter (dB/cm).

- It is dependent on both the frequency of the sound beam and the type of tissue through which it travels.

- As frequency increases, the attenuation coefficient increases.

- In soft tissue the attenuation coefficient averages approximately 0.5 dB/cm per MHz.

Example: a 5 MHz beam has an attenuation coefficient of approximately 2.5 dB/cm.

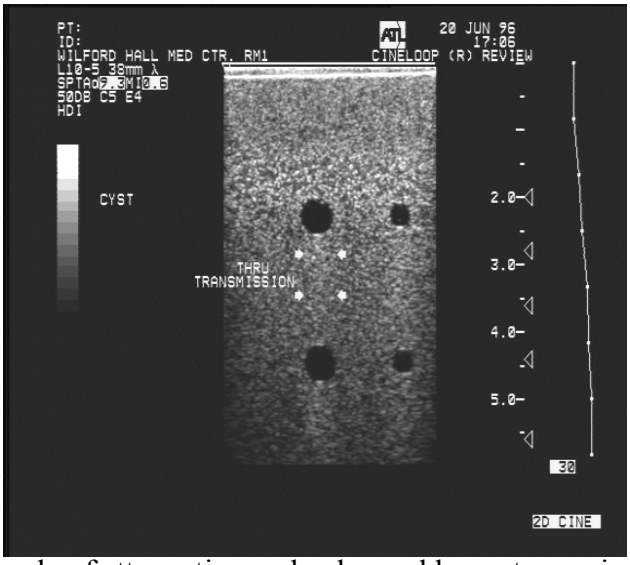
To calculate the total amount of attenuation, multiply the attenuation coefficient by the distance traveled:
Total Attenuation (dB) = coefficient (dB/cm) × d (cm)

Example: Calculate the total amount of attenuation for a 3 MHz beam passing through 10 cm of liver tissue.

Atten. Coeff. = 0.5 dB/cm × 3 MHz = 1.5 dB/cm

Total Attenuation = 1.5 dB/cm × 10 cm = 15 dB

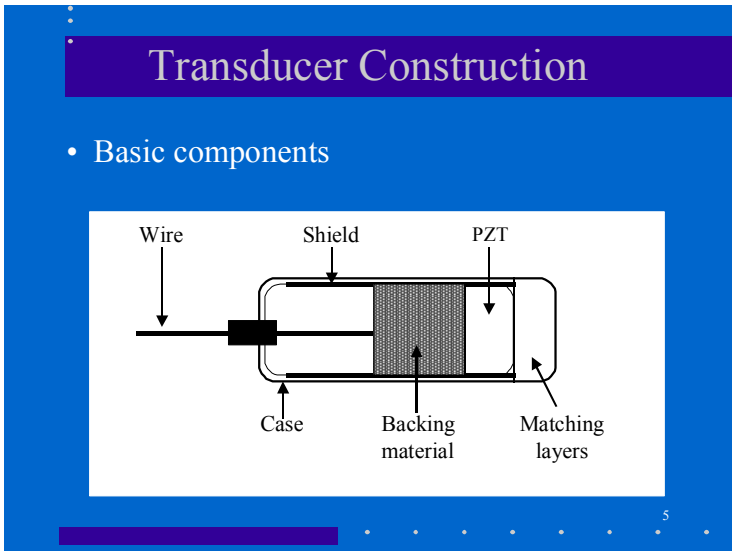
Since attenuation increases with frequency, it should be apparent that higher frequencies do not penetrate as well as lower frequencies. Therefore, we must use lower frequencies to image objects deep within the body even though the lower frequencies provide poorer image resolution. However, we can use the properties of attenuation to our advantage in imaging by selecting acoustic "windows" into the body which have lower attenuation coefficients than adjacent structures. We use the liver as a window to the right kidney, which can be obscured by highly attenuating bowel gas if a lower scanning field is attempted. We use a fluid filled bladder as a window to the uterus and ovaries. Structures that have a significantly lower attenuation coefficient than surrounding tissue provide *echo enhancement (increased through transmission)* because they allow more of the beam to penetrate to deeper structures.



Example of attenuation and enhanced beam transmission

Transducer Basics

Piezoelectric Transducer Construction



The Piezoelectric Effect

Transducer—any device that converts energy from one form to another. Examples: plants, electric and gas powered motors, solar panels, etc.

Piezoelectric—(literally: pressure-electric) Refers to a material that emits an electric signal when exposed to pressure (such as sound vibrations). The reverse is also true; when a piezoelectric material is subjected to alternating electric current, it vibrates.

- Original piezoelectric elements were made of quartz. Quartz is still used in therapy units.

Transducer elements

Modern elements use ceramic crystals–the most common being ***lead zirconate titanate (PZT)***

- More easily shaped and molded in production to optimize beam characteristics.
- Must be polarized so that it will exhibit piezoelectric properties. This is done by heating to 365° C (the Curie temperature) and running an electric current through the crystal as it cools to semi-align the magnetic poles of the crystals.
- Excessive heating can depolarize transducers!

Composite ceramic elements

- Grooves are ground into the face of the element and filled with epoxy
- Advantages: (1) lower acoustic impedance, (2) wider frequency bandwidth, and (3) more sensitive.

Transducer construction

Basic components (single element, unfocused probe).

Piezoelectric element—thickness determines resonance frequency. Thicker elements resonate at a lower frequency

- Resonance frequency is the frequency at which the element naturally rings if excited by an electrical pulse.
- Transducers are most efficient at converting energy if operated at their resonance frequency.
- Continuous wave transducers emit sound frequency equal to the electrical frequency of the excitation voltage applied to the ultrasound element.
- **NOTE:** Pulsed wave transducers emit sound frequencies according to their resonance frequency.

Backing material—stops the element from ringing after the excitation pulse by *damping* the element.

- Allows for shorter pulses of sound which, in turn, increases axial resolution.
- Must have acoustic impedance similar to piezoelectric element to reduce reflection of sound back into the element.
- Must also absorb sound well. Epoxy resin mixed with tungsten powder is often used as a backing material.

Impedance matching layers—reduce reflections at transducer-tissue interface.

- Provide efficient transmission of sound waves from the transducer element to soft tissue and vice versa.
- Matching layer has impedance value between that of the element and soft tissue.

$$Z_m = \sqrt{Z_{st} \times Z_t}$$

- Matching layer is exactly ¼ wavelength thick (remember that wavelength is dependent on frequency).
- Since pulsed transducers emit a spectrum of frequencies, multiple matching layers are needed.

Transducer Characteristics

Frequency characteristics

Dampened transducers produce a pulse containing a range of frequencies rather than a single frequency. The range is centered at the resonance frequency of the transducer element and is called the *frequency bandwidth*. Example: Typical spectral analysis of a 5MHz pulsed transducer. The shorter the pulse duration, the wider the frequency bandwidth.

Spatial resolution

Definition: How closely positioned two reflectors can be to one another and still be identified as separate reflectors on an image.

Axial Resolution—the minimum reflector spacing along the axis of the ultrasound beam that results in separate, distinguishable echoes. Also called longitudinal (or up and down) resolution.

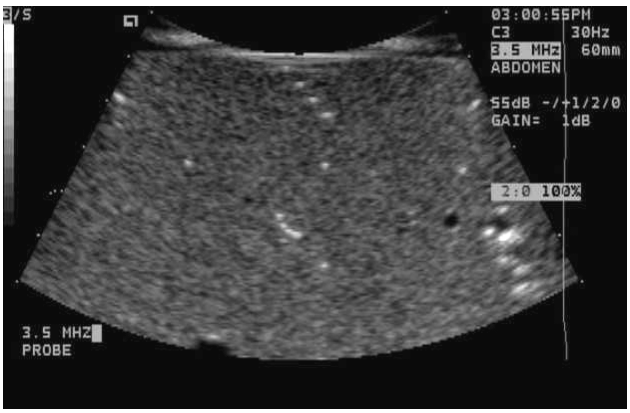
Determined by spatial pulse length (wavelength × # of cycles in pulse). Maximum axial resolution is SPL/2.

- Axial resolution is improved by:
  1) reducing wavelength (increasing frequency), or
  (2) reducing # of cycles in a pulse
  Both are properties of the transducer and cannot be changed by the sonographer.
- **Example:** Two images of the QA phantom using 3.5 MHz and 7 MHz probes, respectively.

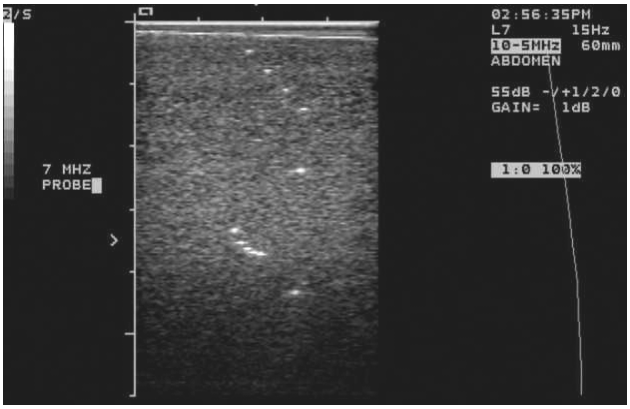
Lateral resolution—the ability to distinguish two closely spaced reflectors that are positioned perpendicular to the axis of the ultrasound beam.

- Also called side-by-side resolution.
- Determined by beam width.
- Specifically, lateral resolution is equal to the beam width.

Axial Resolution

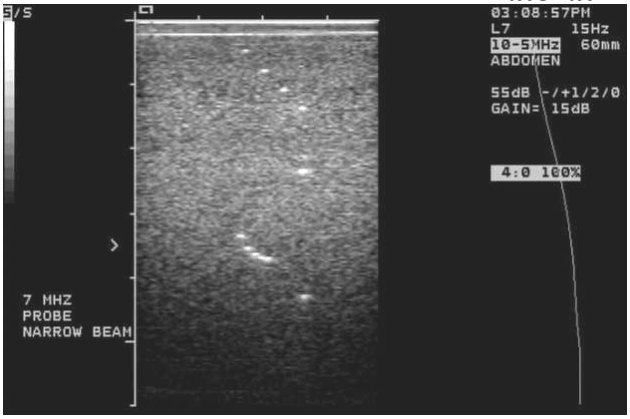


3.5 MHz Probe

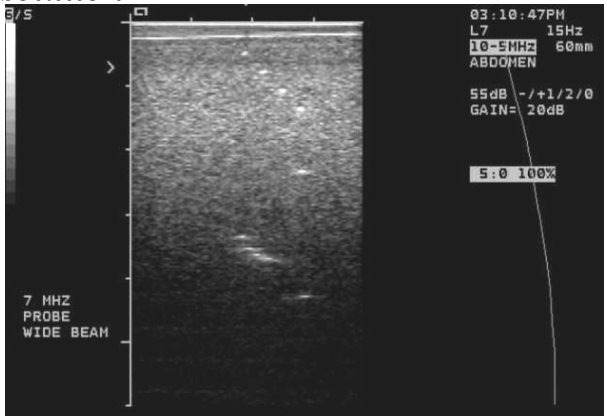


7 MHz Probe

Lateral Resolution



Narrow Beam

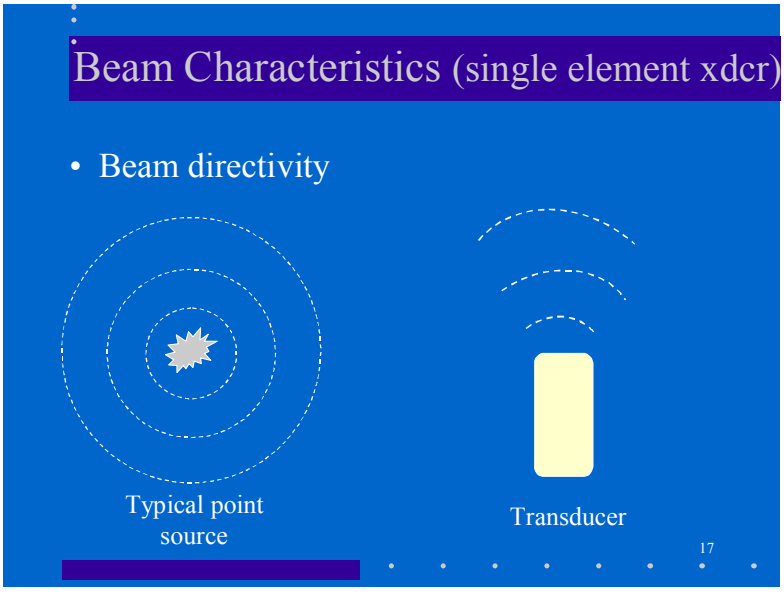


Wide Beam

Beam characteristics (for single element, unfocused transducers.)

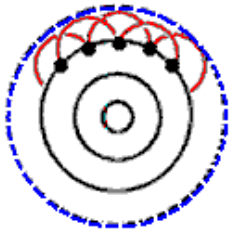
Beam directivity

Typical sound sources send out sound waves in all directions. Analogous to a light bulb or a man speaking. Transducers send out sound primarily in only one direction analogous to a searchlight or a man with a megaphone. This concentrated beam of sound is swept back and forth over the region of interest to produce an image.



Huygen wavelets

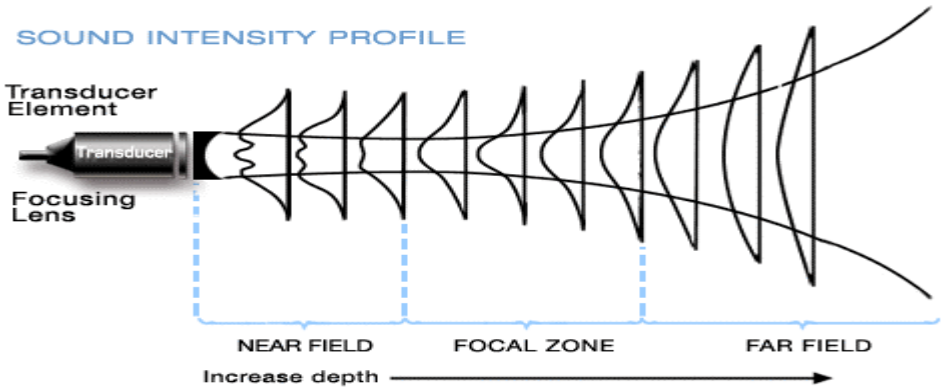
An ultrasound beam is actually composed of many small sources of sound from the face of the transducer.
Each of these sources gives off a small wave called a *Huygen wavelet*.
The strength of the beam at any given point is a result of the interactions of these wavelets with one another.
Interference among the waves helps shape the total beam.



Under Huygen analysis, a wavefront consists of an infinite number of wavelets.

Near field versus far field

In single element, unfocused transducers the beam characteristics change dramatically with distance. This leads us to divide the beam into two fields: near and far.
The near field (also called *Fresnel zone*) is characterized by a tightly collimated beam that fluctuates widely in intensity and amplitude.



The near field length (NFL) depends on the diameter of the transducer element (d) and on the wavelength (λ) of the sound. Specifically, $\mathbf{NFL = d^2 \div 4\lambda}$

As transducer diameter increases, NFL increases. As wavelength decreases, NFL increases. The best spatial resolution occurs at the NFL.

The region beyond the near field is called the far field (or *Fraunhoffer zone*). The far field is characterized by a uniform, but diverging beam.

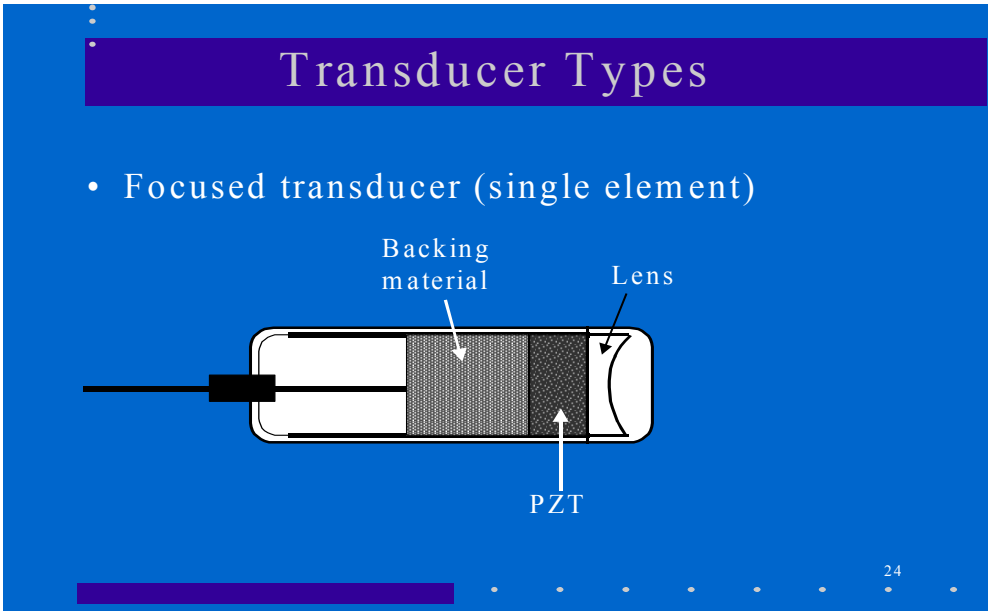
Side lobes

- Offshoots of energy that are not part of the main beam.
- Occur in the focal zone and far field.
- Degrade lateral resolution
- Minimized by pulsing the beam and also by a process called apodization (discussed later).

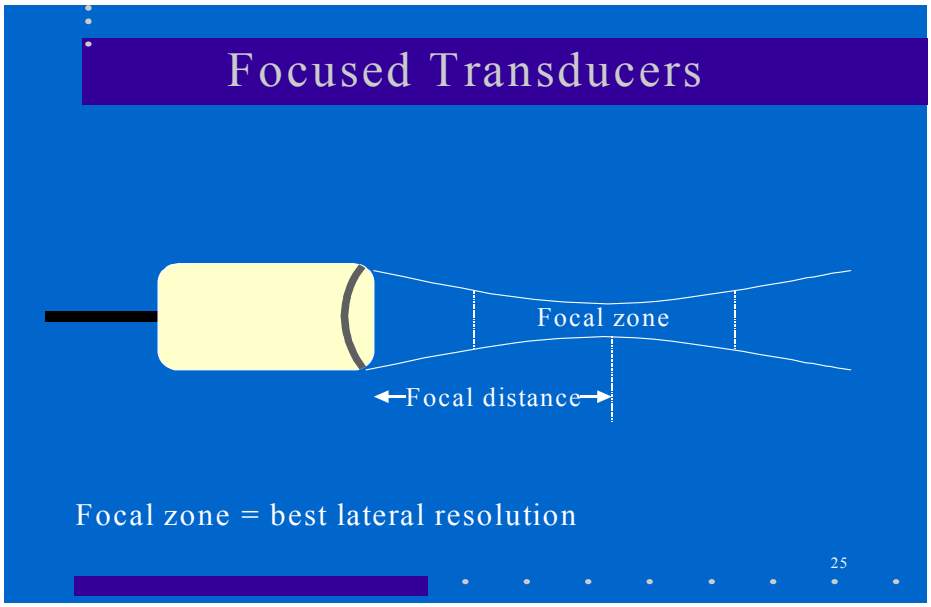
Transducer Types

Focused transducers

Unlike x-rays, sound waves can be focused either electronically or by using an acoustic lens. Focusing provides better lateral resolution.



Single element transducers are focused by molding the piezoelectric element or by adding a curved acoustic lens in contact with the element. Focusing has the effect of narrowing the beam width for a certain distance beyond the transducer face. The narrowest part of the focused beam is called the ***focus***. The ***focal distance*** is the distance from the transducer face to where the beam reaches its smallest diameter. The ***focal zone*** is the region surrounding the focus where the beam width is less than two times the width at the focus. The focal zone provides the best lateral resolution. Single element transducers have fixed focal zones that cannot be adjusted by the sonographer. Single element transducers are not used for imaging purposes.

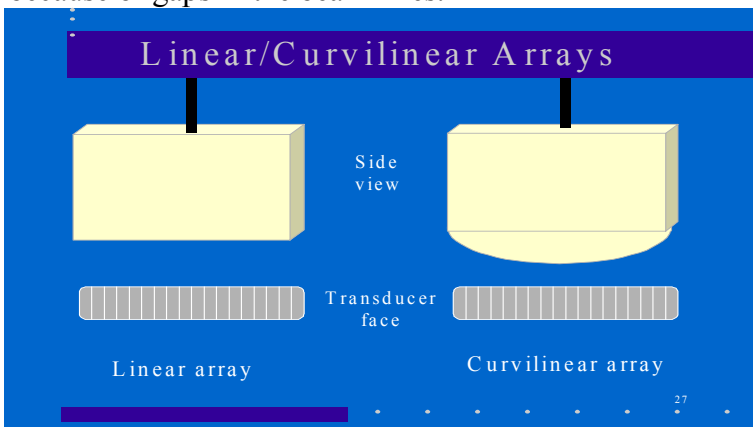


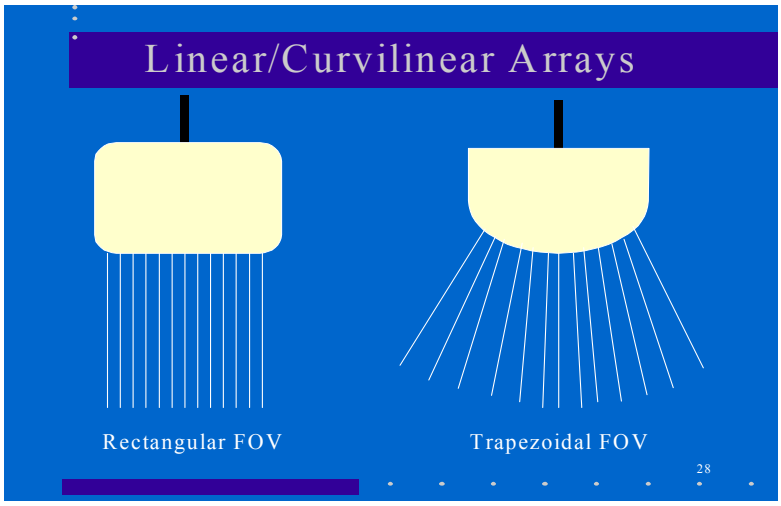
Transducer arrays

Modern imaging transducers *do not* use single elements, but rather *arrays* of elements. An array is a series of small elements placed close together. This allows the machine to excite groups of elements to control and shape the beam.

Linear/Curvilinear

- Rectangular shaped elements arranged side by side
- The entire array will consist of 120 to 250 or more elements.
- The elements are usually fired in groups of 20 or more in sequence across the entire array.
- The linear array produces a rectangular field of view with uniform lateral resolution throughout the field.
- The curvilinear array produces a trapezoidal (wedge-shaped) field of view. This has the effect of giving a greater field of view, but poorer lateral resolution in the far field because of gaps in the beam lines.



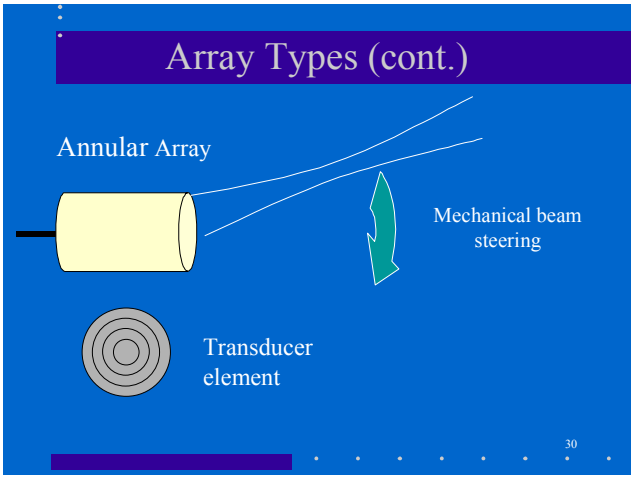


Phased Array

- Look like small linear arrays.
- Consist of 128 very thin elements.
- All elements are fired together to produce a pulse.
- The pulse is steered electronically using time-delay sequences that we will discuss later.

Annular Array

- Consist of concentric circular elements arranged in a target pattern.
- All elements are fired together to create a pulse.
- Beam is focused in all directions.
- The beam is swept mechanically across the imaging field.



Beam Formation With An Array

Individual elements are very small and unfocused, but together, they reinforce one another. Destructive interference can be created firing the outer elements in a group

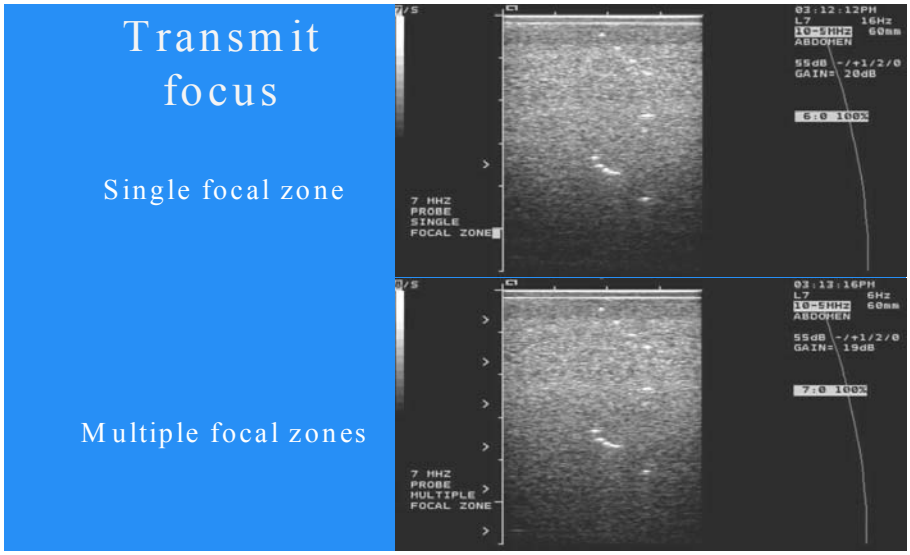
slightly before the middle elements. This cancels out the portions of the beam that tend to diverge leaving a well-focused beam.

Transmit Focus

The electronic focusing of arrays allows the sonographer to adjust the transmit focal distance to maximize detail in the area of prime interest. Array transducers also permit simultaneous *multiple transmit focal zones*.

- Greatly increases the focal region of the transducer
- Accomplished by firing multiple sound pulses, each focused at a different depth along the beam and reconstructing a single image using information from all the separate pulses.
- The disadvantage to multiple transmit focal zones is a slower frame rate.

Example: single versus multiple focal zones.



Apodization

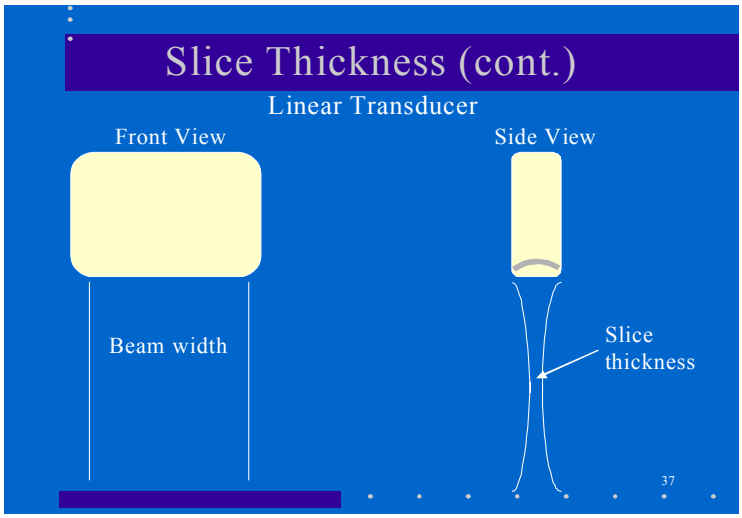
The process by which the inner elements in an array are given greater excitation and echo sensitivity than the outer elements to reduce the effects of side lobes. This process enhances lateral resolution by narrowing the beam width.

Channel Size

A *channel* in an ultrasound unit refers to the individual transducer element and the pulse-receiver circuit to which it is connected. The number of channels available controls how many elements can be simultaneously activated. Common channel sizes are 48, 64, and 128. Larger channel sizes are generally better because they provide for a more focused beam, especially in the far field. Hence, better lateral resolution.

Slice Thickness

Slice thickness represents the third dimension in resolution. We have already discussed the first two: axial and lateral. Slice thickness refers to the thickness of the section of tissue that is represented in the two-dimensional image. The size of the beam *perpendicular* to the image plane. Just like in CT, a large slice thickness means poorer resolution because objects smaller than the slice thickness can be lost due to volume averaging.

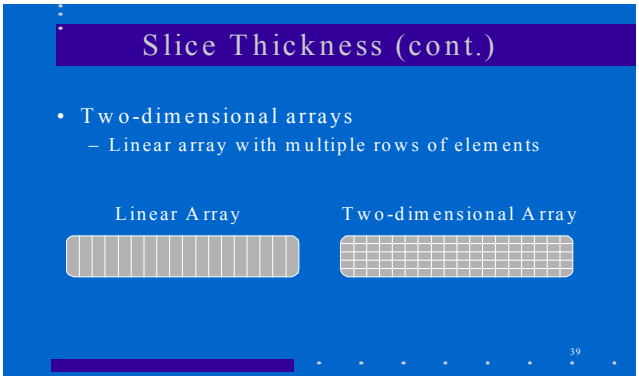


Controlling Slice Thickness

In annular transducers, the slice thickness is the same as the lateral resolution because the beam is focused in all directions. For linear, curved, and phased arrays the slice thickness is controlled by an acoustic lens. Therefore the thickness is fixed and cannot be adjusted. Slice thickness is the worst measure of resolution for array transducers (with the exception of annular arrays).

Two-dimensional arrays

A new approach to the slice thickness problem is the two-dimensional array. It is a linear array with multiple rows of elements. It allows for electronic focusing of slice thickness as well as beam width.



Transducer Damage

Transducers cost many thousands of dollars. They should be treated with the utmost care. Damage to transducers can come from several sources:

- Excessive heating can cause depolarization of the transducer element at the Curie temperature and other damage at lower temperatures. ***Transducers should never be autoclaved or heat sterilized!***
- Dropping a transducer can crack the piezoelectric element and/or the case. That would be ***very bad***.
- Damage to the transducer surface can be caused by using the wrong cleaning agents. Consult the operator's manual for proper cleaning instructions.
- Damage to cables can result from excessive twisting or from running them over with the wheels of the ultrasound unit. Be careful!

Pulse-Echo Ultrasound Instrumentation

The Range Equation

Q: How do we determine the distance from the transducer to a reflector?
A: By measuring the length of time it takes for a pulse to return.

$T = 2D/c$ or $D = cT/2$
Where:

T = echo return time
D = distance from reflector to transducer
c = speed of sound
The "2" is present because the sound must travel there and back.

Example: What is the distance from the reflector to the transducer if the echo return time is 195 microseconds?
Solution:

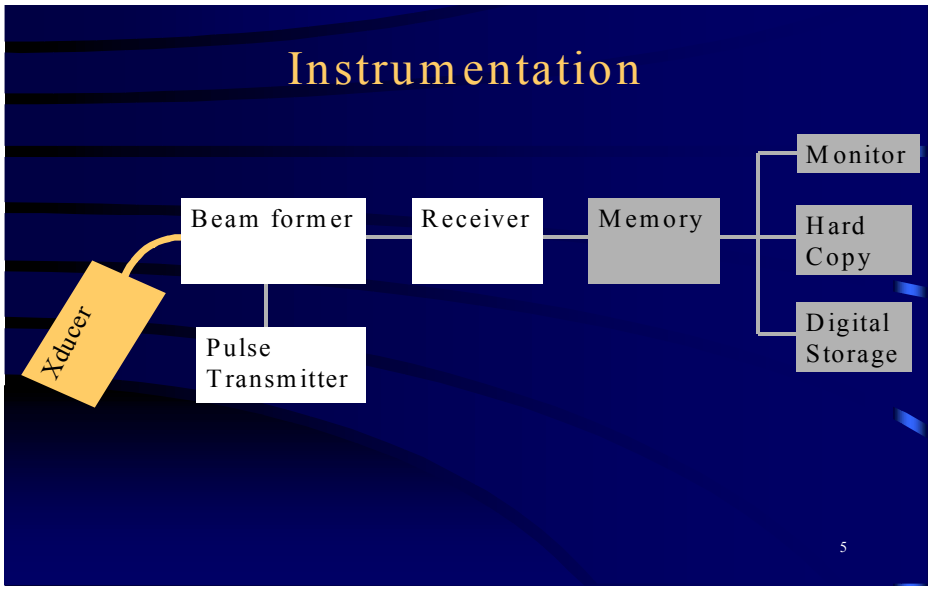
$D = 1.54 \text{ mm/}\mu\text{sec} \times 195 \ \mu\text{sec} \div 2$
$= 300.3 \div 2$
$= 150.15 \text{ mm or } 15 \text{ cm}$

Ultrasound machines use 1540 m/sec as the average speed of sound in soft tissue for computing all distances.

Instrumentation

A typical ultrasound machine consists of the following components: transducer, beam former, transmitter, receiver, memory, monitor, hard copy device, and digital storage device. In the previous unit, we discussed transducers. Now we will talk about the next

three components in this list: the beam former, transmitter, and receiver. Unit 8 covers the remaining components.



Beam Former

Purpose: To shape the beam. The beam former controls electronic focusing, dynamic receive focus, and electronic sweeping (phased arrays only).
How? By providing pulse-delay sequences to the individual elements of the array as discussed in unit 6.

Types: **Analog and digital**

- Analog devices are devices that use physical quantities (such as electrical signals) to represent data. Analog beam formers process the actual electric pulses received from the transducer elements. (The currents are digitized at a later stage of image processing.)
- Digital beam formers convert echo signals into digital (numerical) information and process the information with a computer.

The stability, programmability, and broadband nature of digital beam formers are rapidly making them the predominant of the two beam former types.

Pulse Transmitter

Purpose: To provide electrical signals for exciting the transducer element. Sets the pulse-repetition frequency (PRF) based on operating mode and imaging depth
Controls output power (amplitude and intensity) as selected by sonographer. Output power is measured in dB.
Controls the overall strength of the pulse, and therefore, the returning echoes. Increased power allows visualization of weaker echoes.

- Power output affects acoustical exposure to patient. This is an important factor in early obstetrical exams. ALARA principle—keep patient exposure "As Low As Reasonably Achievable" within the confines of the examination. *Minimize power settings and exam time.*

Receiver

Accepts signal information from the beam former and processes it for display.

Gain—amplification of echo signals for display.

- Usually expressed in decibels.
- May be expressed as a ratio.

  Example: If received echo signals are amplified 100 times (a ratio of 1 to 100), this is equivalent to how many decibels of gain amplification?:

  $dB = 20 \log (A2/A1)$
  $= 20 \log (100/1)$
  $= 20 \times 2$
  $= 40dB$

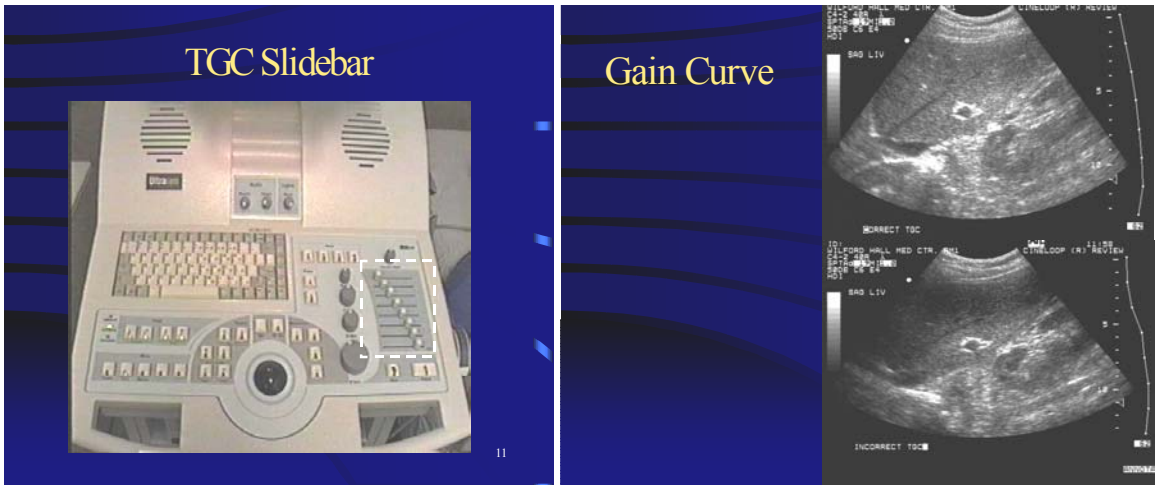
Types Of Gain

Overall gain control

- Increases amplification at all depths.
- Has **no effect** on patient exposure.

Swept gain (TGC–time gain compensation)

- Makes adjustments for attenuation as depth increases. Echoes received from a greater depth may be amplified more.
- Slide bar control. Most common and convenient TGC control. Uses indicators on screen to correspond to each slide bar.
- 3-knob control. Uses one knob for near gain, one for slope, and one for far gain.
- Gain curve and slope.
  The gain curve appears next to the image on the screen. The slope of the curve should correspond to the amount of attenuation present in the tissue



Internal time-varied gain

Newer machines provide an automatically swept gain in addition to operator adjusted gain. This feature automatically boosts gain to more distant echoes, thereby minimizing operator adjustments.

Dynamic Frequency Tuning

- Makes best use of frequency bandwidth of pulsed sound
- Listens preferentially for higher frequencies in the near field and for progressively lower frequencies at greater depths.

Reject Control

- Used to eliminate low level noise and low-level echoes from the display without affecting large amplitude echoes.
- Reject may be thought of as a threshold for display of signal intensities. Echoes below the set threshold will not be displayed.
- The reject control on the Aspen is the "filter" key. It only functions during Color and Pulsed Wave Doppler (not during B mode imaging).

Dynamic Range

The range of signal amplitudes over which a device will respond. Signals above and below the range will not be processed. Dynamic range is different for each component of the ultrasound machine.

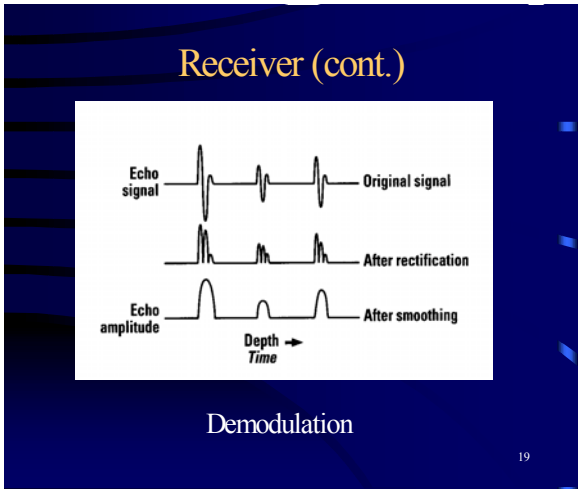
Examples:
Receiver—100-120 dB
Scan converter—40-45 dB
Monitor—20-30 dB

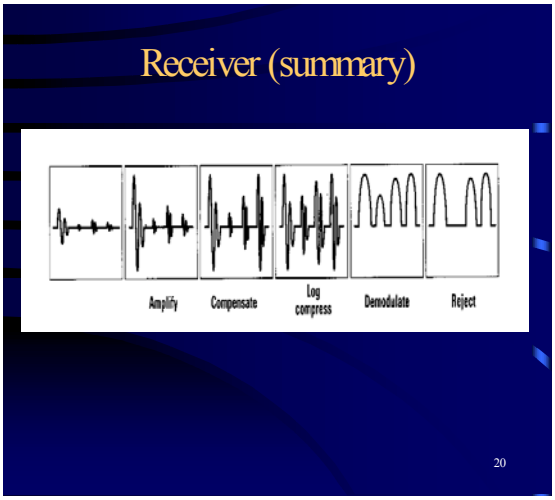
Compression

Ultrasound machines use logarithmic amplification to represent a large range of echo signals on a smaller scale. This makes the best use of the large receiver range on the limited monitor range. For example, a 110 dB dynamic range setting

compresses 110 dB of receiver range into the 20-30 dB range of the monitor. Higher dynamic range settings use more compression to represent more echo intensities on the image. Therefore, higher dynamic-range settings result in a longer scale of contrast. Lower settings result in a shorter scale of contrast.

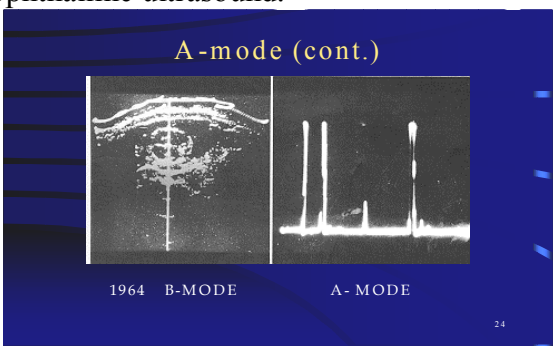
Demodulation
Converts the multiple vibration echo signal into a single positive pulse for display. First the demodulator rectifies the pulse, then it lumps the pulse under a single "envelope."





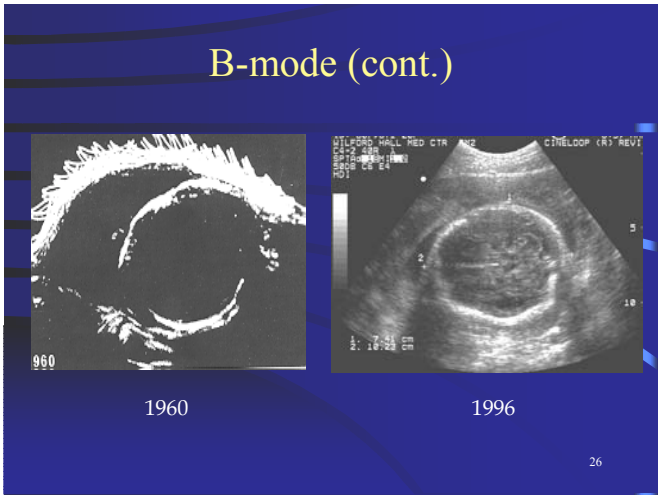
Display Modes
The information gathered by the ultrasound machine can be represented in several different ways for interpretation by the viewer. The specific method of representation is called a display mode. There are four display modes that have typically been used in ultrasound: A-mode, B-mode, M-mode, and Doppler

A-mode (Amplitude mode)
Reflectors are represented as spikes on an oscilloscope-type display. The height of the spike represents the strength of the returning echo. The distance between spikes represents the distance between interfaces. This is the least frequently used display mode currently used only in ophthalmic ultrasound.



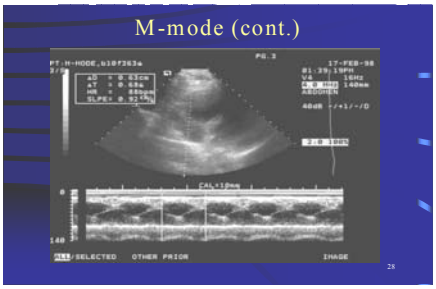
B-mode (Brightness mode)

Echoes are represented as dots on a screen that combine to form an image (like a TV image). Echo strength is represented by the brightness of the dot. The distance from the dot to the top of the screen represents the distance of the echo from the transducer. This is the most commonly used display mode in modern ultrasound imaging.



M-mode (Motion mode)

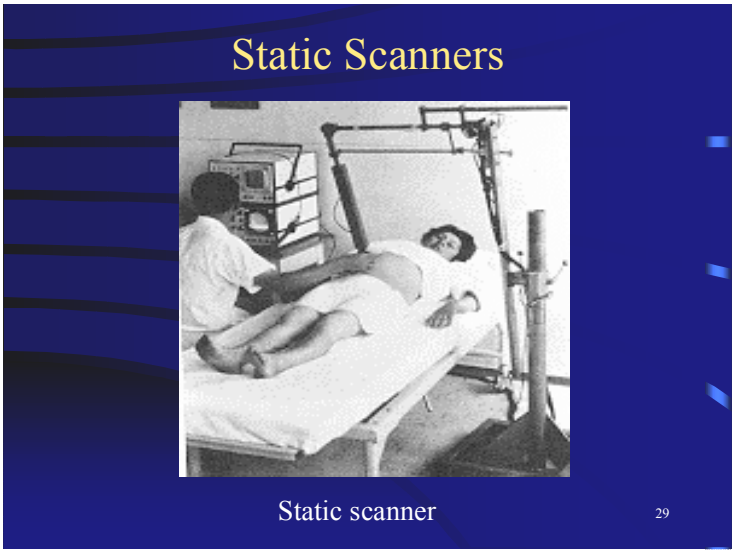
Used to study rhythmically moving objects (most commonly the heart). M-mode appears as a tracing that scrolls across the screen (usually from left to right). The vertical axis of the tracing represents the distance from the reflector to the transducer. The horizontal axis represents time in seconds. For this reason, M-mode is sometimes called TM-Mode (time motion mode). The tracing will be composed of many horizontal lines with each line representing a reflector in the path of the ultrasound beam. Stationary reflectors project a straight line. Moving reflectors, such as the valves of the heart, project lines that curve up and down as the distance from the reflector to the transducer varies with time. M-mode is most frequently used in conjunction with echocardiography (although less so than in the past). Although some facilities use an M-mode tracing to document fetal heart motion and to measure fetal heart rate.



Static Scanners

Original B-mode scanners that processed one image at a time.

- Used single element transducer connected to a mechanical arm.
- Transducer was mechanically swept across area of patient to be imaged.
- Single, large-field image was produced similar to CT or MRI. Each image took several seconds to process.



Real-time Scanners

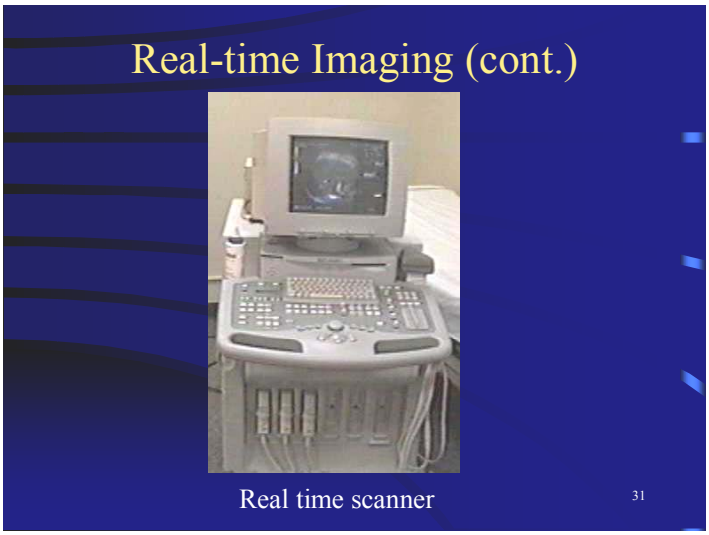
A form of B-mode in which the image is updated many times per second giving the appearance of live "motion pictures" of the anatomy.

Image build-up—As the sound beam sweeps through the tissue, the image is swept onto the screen.

- With each progressive sweep of the beam, the image is updated.
- In real-time imaging the beam sweep is so rapid, it is unnoticeable to the human eye.

Real-time scanners

- Use array transducers .
- Allow rapid beam sweeping.
- More powerful computers allow faster image reconstruction.



Frame Rate

The number of frames per second. (The number of times per second the transducer sweeps the ultrasound beam).

Frame Rate = 1 ÷ **Frame Time**

(as Frame Time increases, Frame Rate decreases)

Frame Time = (# of beam lines)(echo return time per line)

Echo Return Time = (13 µsec/cm)(distance traveled)

The echo return time per line is the product of the sound travel time (approximately 13 µsec/cm in soft tissue) and the distance traveled (to the reflector and back).

Since the speed of sound in soft tissue is 1.54 mm/µsec, it takes 6.5 µsec/cm for sound to travel through one cm of soft tissue one way (use formula T=2D/c converting for centimeters) or 13 µsec/cm both ways.

Therefore: **Frame Time** = (# of beam lines)(13 µsec/cm)(distance traveled)

The maximum allowable frame rate is number of frames per second (the reciprocal of the total time required per frame). For example, if the frame time is 0.1sec (1/10sec), the maximum frame rate is 10 frames per second.

In a practical sense, the following machine settings control frame rate:

Imaging depth—the greater the depth, the slower (decreased) the Max Frame Rate (increased the Frame Time).

The number of beam lines—this is a property of the selected transducer, but can be controlled by reducing the field size. More beam lines mean slower (decreased) Max Frame Rates (increased Frame Time).

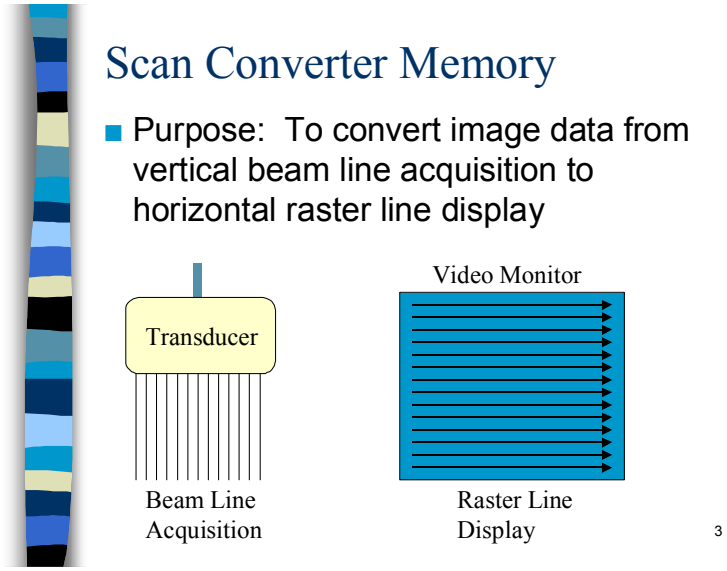
The number of focal zones—each focal zone requires a separate pulse per beam line. Increasing the number of focal zones slows (decreases) the Max Frame Rate (increases the Frame Time).

Image Storage and Display

Scan Converter Memory

The Scan Converter

Image data is acquired from the receiver along the (more or less) vertical beam lines. Television monitors build images along horizontal *raster* lines. The scan converter stores images during scan build-up for viewing and recording. The scan converter enables image data to be viewed on video monitors.



Digital Devices

Digital devices use binary numbers to represent information as opposed to the physical quantities (such as electrical currents or springs and gears) used by analog devices. The basic unit of a digital device is a simple electronic circuit called a binary digit or *bit*. The bit has an on position and an off position that represent 1 and 0, respectively. Each number is a piece of information to the machine. Series of numbers are used to store all types of information. Binary numbers use a base of two rather than the base ten decimal system we are accustomed to. Each column of a binary number represents the number "2" raised to a progressively higher power (i.e., 2^0, 2^1, 2^2, 2^3, …, 2^n). Example: The decimal number 75 can be rewritten in binary form as 1001011.

Proof:

2^6 (64)	2^5 (32)	2^4 (16)	2^3 (8)	2^2 (4)	2^1 (2)	2^0 (1)
1	0	0	1	0	1	1
64	+0	+0	+8	+0	+2	+1 = 75

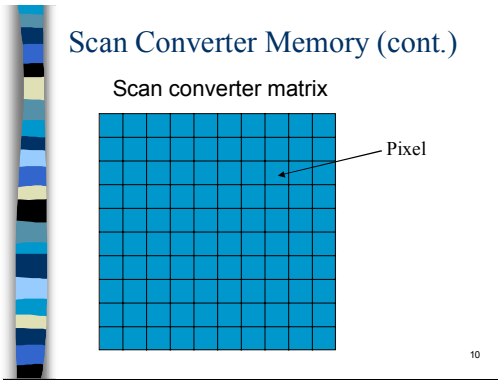
An eight-bit storage unit is called a *byte*. One byte can represent all the numbers between 0 and 255, or 256 separate numbers.

Analog To Digital Converter (A/D converter)
Accepts the analog electrical signals from the transducer and assigns numbers to each pulse representing the relative strength of the echo. The number of bits assigned to digitization determines the number of discreet levels that may be represented after digitization.

Use the formula $L= 2^n$ to determine how many levels an *n*-bit storage unit can represent.
Example: 3-bit digitization can only represent 8 signal levels ($2^3 = 8$). The entire range of signal intensities would be broken into only 8 distinct levels after digitization. Eight-bit digitization, on the other hand, would allow for 256 discrete signal levels after digitization ($2^8 = 256$).

A/D conversion can be accomplished at any point in signal processing between the beam former and the scan converter.

Scan Converter Matrix
Scan converter memory is arranged into a matrix with each box in the matrix representing a part of the image being reconstructed. For this reason, each box in the matrix is called a picture element or *pixel*. Information from echo signals is inserted into the matrix at pixel locations corresponding to reflector positions in the body.



Read/Write Mode
The term *write* refers to placing information into the image matrix. Data from the image matrix is "read" and sent through a digital-to-analog converter to make it suitable for display on a TV monitor. While the machine is in scan mode, it is

continuously writing information to and reading information from the scan converter. When the machine is in freeze mode, no new information is being written to the scan converter. However, image data continues to be read and sent to the monitor.

Image Resolution

Gray Scale - The number of bits assigned to each pixel of the image matrix determines how many different amplitudes (shades of gray) can be displayed by the pixel. In general, the more shades of gray the machine is capable of demonstrating, the better the image resolution.

Matrix Size - Matrix size refers to the number of rows and columns of pixels within the matrix.

- Common matrix sizes are 512×512 or 1024×1024.
- The larger the matrix size, the smaller the individual pixel.
- Smaller pixels means better *spatial* resolution.
- Example: 10×10 and 5×5 matrices.

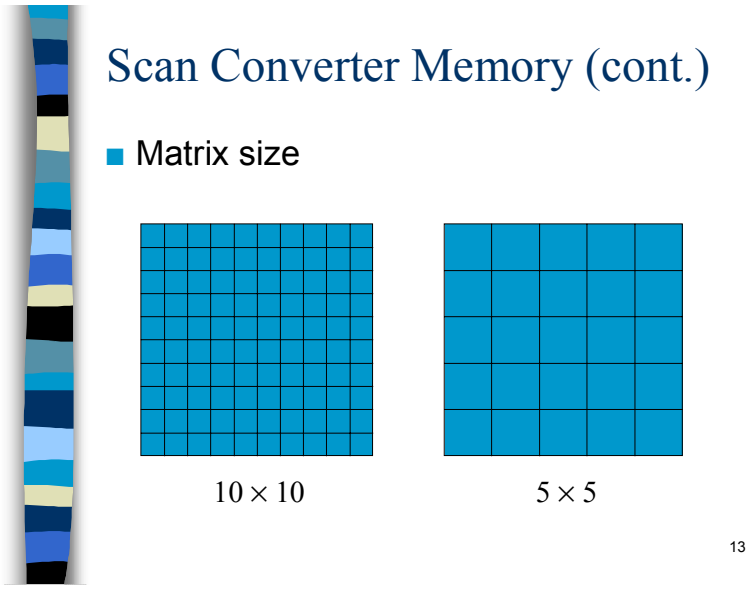


Image Magnification - Enlarging a portion of the image field. There are two basic types of image magnification that different manufacturers use: read zoom and write zoom.

Read Zoom - Taking existing data from the scan converter and enlarging a portion of the data to fill the whole monitor screen.

- Advantage—read zoom may be accomplished on a frozen image.

- Disadvantage—one pixel of the scan converter matrix is enlarged to fill many pixels on the monitor. This may cause a pixelated appearance on the monitor.

Write Zoom *(RES In Acuson Terminology)* - A portion of the image is selected in real-time (usually by drawing a box around the area) and then the selected area is rescanned. Echo data from the selected area only is written to the memory.

- Advantage—better detail.
- Disadvantage—cannot be performed on a frozen image.

Pre-And Post-Processing

Processing—manipulation of the echo signal data to tailor it for viewing.

Pre-Processing - Anything done to the echo signal before it reaches the scan converter.

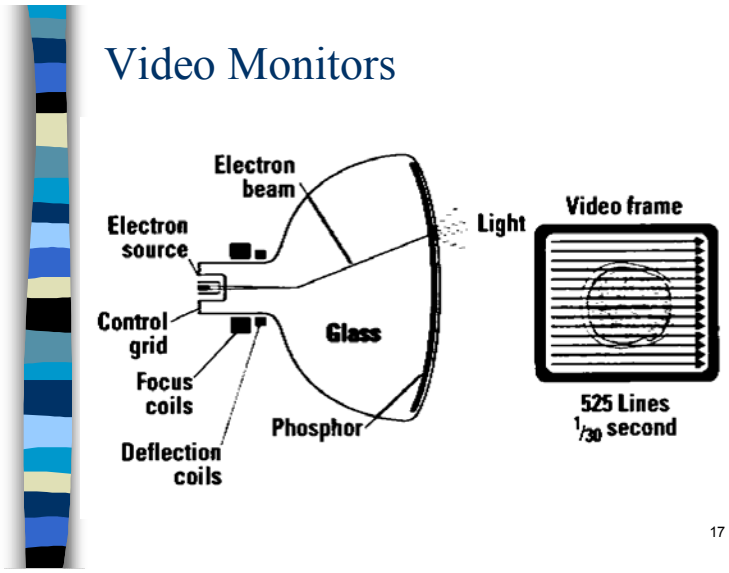
- Includes: **gain amplification, compression, reject control, edge enhancement, and demodulation** (among other things).
- Can only be performed during real-time "scan" mode.

Post-Processing - Manipulation of ultrasound data stored in the scan converter memory.

- May be performed on real-time or frozen images.
- Usually involves manipulation of the gray scale (the level of brightness assigned to each number in the image matrix).
- There are usually a number of post-processing curves to choose from. Select the one that looks best for the application you are performing.

Video Monitors

Components: electron source, control grid, focus coils, deflection coils, and phosphor screen.



Operation:

- Receives signal from scan converter memory.
- Fires tightly focused electron beam at phosphor screen
- Deflection coils direct beam
- Scan begins at top left corner moving horizontally to the right. Then it starts the second line below the first, again moving from left to right.
- The phosphor screen glows as it is struck by the electron beam. Beam strength is varied to produce different shades of gray.

There are 525 raster lines in a standard video monitor. It takes 1/30 of a second to scan the entire field. To reduce image flicker, the field is divided into two sections by odd and even lines. The first section is scanned in 1/60 of a second. Then the second section is scanned in between the lines of the first. Color monitors have elements that are composed of red, green, and blue phosphors. Three separate electron guns activate the different colors to produce any shade.

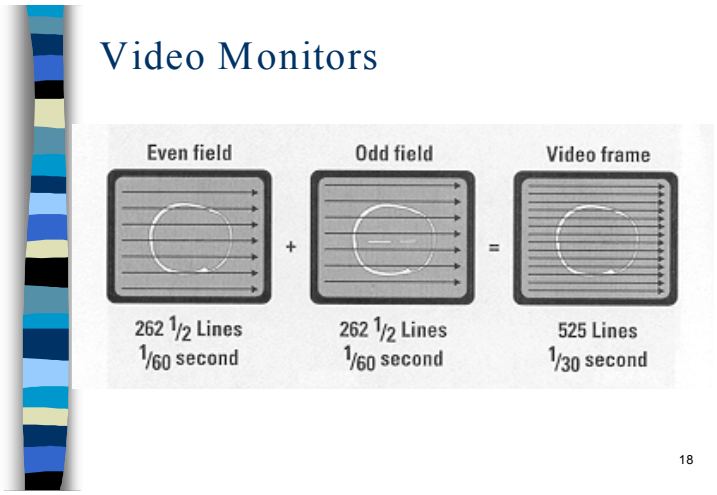


Image Recording

Multiformat Cameras
Multiformat cameras use single emulsion x-ray film (usually 8×10") and special cassettes without screens. They use a high quality internal monitor to expose the film. Typically, six ultrasound images are recorded on a single sheet of film. The films are then processed in a standard darkroom with an automatic processor.

Laser Cameras
Special red-light sensitive 14×17"(laser) film is loaded into a large supply magazine. A tightly focused laser light that is deflected across the film using mirrors exposes the film. The laser intensity is varied to produce different shades of gray on the film. Typically, twelve ultrasound images are recorded on a single film. The film may be developed using a standard automatic processor or a processor can be connected directly to the laser camera. Laser cameras produce excellent quality images in terms of detail and gray scale.

Thermal Printers
Thermal printers print images onto a roll of thermal paper. Image quality is somewhat poorer than multiformat or laser cameras. However, cost is substantially lower and there is no need for a darkroom or film processor. Thermal printers are generally used in facilities with low patient flow or with limited need for image documentation (such as L&D units). They are also useful for cardiology studies to record M-mode tracings.

VCR's
VCR's are used in some cardiology applications, small clinics, and occasionally in radiology departments to document all or part of a real-time examination. Disadvantages include the length of time required to review the case and the increased space needed to file the bulky tapes.

Computer Storage
Another advantage of digitized images is the ability to store them in computer imaging systems for viewing on a display monitor at a later time. Some departments rely almost completely on computer storage and display, virtually eliminating the need for hard copy images.

Magneto-Optical (MO) Disks
These are re-writeable laser disks that combine the advantages of optical (laser) and magnetic storage media for digital data. MO disks can hold vast quantities of data like optical (laser) disks, but they can be erased and rewritten like magnetic disks. The MO disk is comprised of a metal alloy. The disc drive heats a small point on the disk above the Curie point for the alloy loosening magnetic crystals

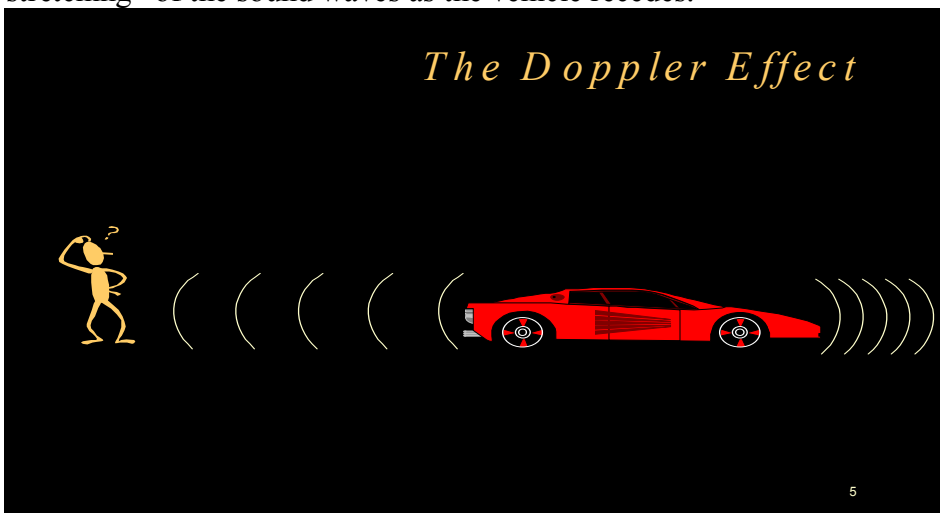
within the alloy. Then a magnetic "write" head is able to store data on the disk in a much smaller point than would be achievable using magnetic media alone.

Doppler/Color Doppler

The Doppler Effect

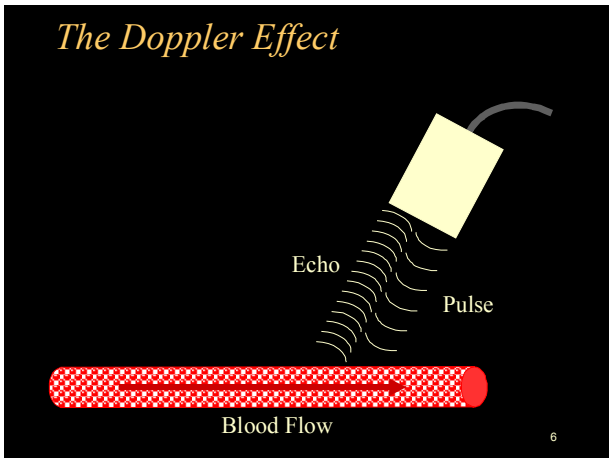
Doppler shifts for audible sounds

- An apparent change in sound frequency when either the sender or receiver is in motion.
- Example: a moving car. Engine noise pitch seems to drop as the car passes by.
- Caused by compression of the sound waves as the vehicle approaches and "stretching" of the sound waves as the vehicle recedes.



Doppler shift in medical ultrasound

In ultrasound, Doppler shifts occur when sound is reflected from moving objects. Reflectors moving toward the sound source (transducer) send echoes of a slightly higher frequency than the original beam. Reflectors moving away from the transducer send echoes of a slightly lower frequency than the original beam. The difference between the transmitted frequency and the received frequency is called the Doppler frequency. Doppler frequencies are usually in the audible sound range.



The Doppler Equation

The Doppler frequency may be calculated using the following equation:

$$f_D = 2f_0 v\cos\theta / c$$

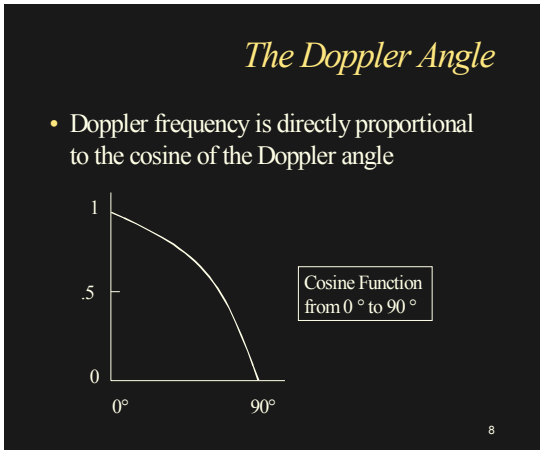
where:

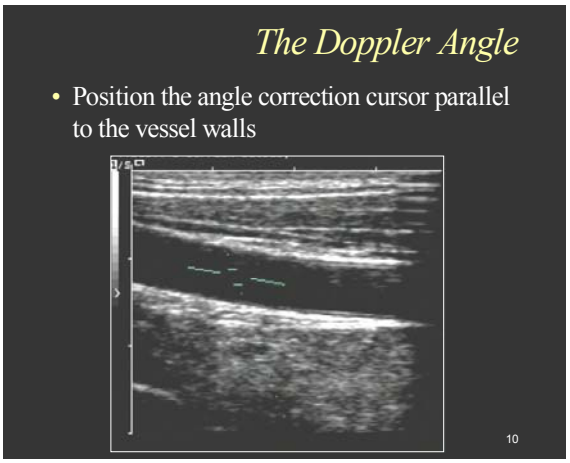
f_0 = transmitted sound frequency
v = reflector velocity
c = speed of sound
cos θ = cosine of angle between beam and reflector path

Notice that f_0, v and cosθ are all on the top of the equation. This means as these values increase, the Doppler shift also increases. Doppler frequency is directly proportional to reflector speed. As reflector speed increases, Doppler frequency increases proportionally. Doppler frequency is directly proportional to ultrasound frequency. Higher ultrasound frequencies produce higher Doppler shift frequencies for the same reflector velocity.

The Doppler Angle

Notice that the Doppler frequency is directly proportional to the cosine of the Doppler angle. This means that as the cosine of the angle gets smaller, the Doppler shift gets smaller. The cosine of an angle decreases from 1 to 0 as the angle increases from 0 to 90 degrees. This means the Doppler frequency will be greatest when the Doppler angle is zero. This is a theoretical situation and is not practically achievable unless the transducer is placed inside the vessel. At a 90 degree Doppler angle, the cosine is zero, therefore, the entire numerator of the Doppler equation becomes zero and there is no detectable Doppler shift. Optimal Doppler readings are obtained with a Doppler angle between 30 and 60 degrees.





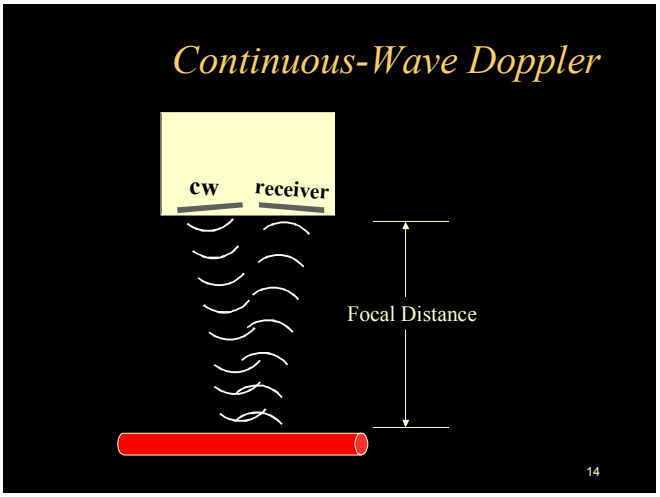
Angle Correction

Because Doppler frequency calculations are dependent on Doppler angle, the ultrasound machine must know what Doppler angle is being used during sampling. The operator inputs the flow angle by adjusting an angle cursor on the B-mode image so that the cursor is parallel to the vessel walls. Errors in angle correction will result in velocity estimation errors. Angle correction errors are more critical as the Doppler angle approaches 90 degrees.

Continuous-Wave Doppler

Description

- Sends a continuous wave of sound into the tissue.
- Uses a separate transducer element to "listen."
- Detects flow anywhere in the path of the beam



CW Instrument Controls

Power control—controls the amplitude of the transmitted beam. Increasing the power setting increases the amplitude of the echoes received and also increases patient exposure.

Receiver control—adjusts the amount of amplification (or gain) applied to the received echoes.

Loudness control—adjusts the speaker volume for the audio signal

Wall filter—removes low frequency Doppler signals from the display. Prevents slow moving structures such as vessel walls from interfering with the output signal.

CW Transducers

CW transducers use two separate elements for transmitting and receiving (CW Doppler can be performed using a standard array transducer.) Elements are tilted inward so that the reflected beam will return toward the receiving element. The point at which the beam patterns cross is the focal distance for the transducer and is the most sensitive region for signal detection.

Frequency Selection For Doppler Ultrasound

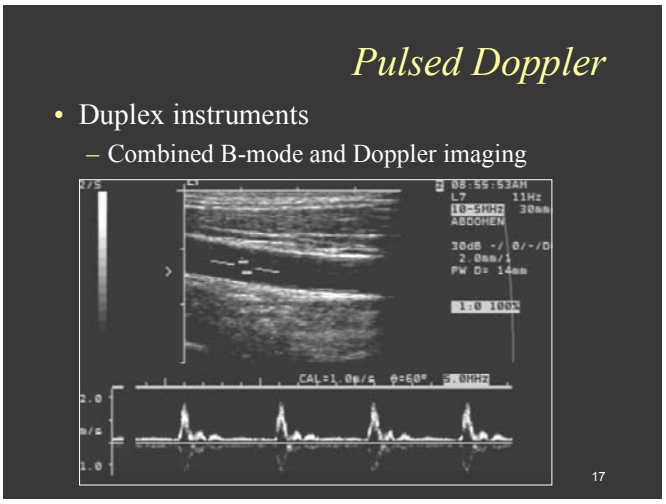
Doppler ultrasound relies on Rayleigh scatterers. Higher frequency beams produce higher intensity Rayleigh scattered signals. However, higher frequency beams are subject to increased attenuation. Sonographers should use the highest frequency that will penetrate to the desired depth.

Pulsed Doppler

Pulsed Doppler allows the sonographer to select Doppler signals from a specific depth using principles similar to pulse-echo B-mode scanning. The selected region of interest is called the *sample volume*.

The transducer sends out several short pulses and listens only for echoes returning from the distance determined by the sample volume setting. It stores echoes from each pulse in temporary memory and compares the echoes received from each pulse with one another. The machine is able to determine which reflectors are moving by comparing the echoes received from different pulses.

The operator can adjust sample volume size by changing the size of the sample volume gate as displayed on the B-mode image. A larger gate will collect echo information from a larger area of interest. In general, a larger gate will display a wider range of velocities. A smaller gate will display a narrower range of velocities. However, gate position becomes more critical with smaller gates.

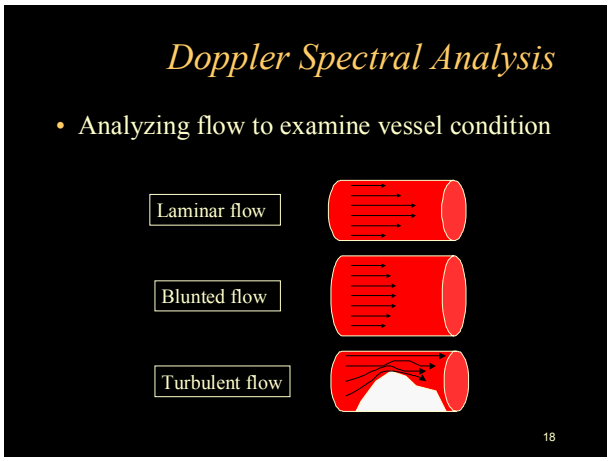


Duplex Instruments

A machine that allows both B-mode and Doppler mode scanning is called a duplex ultrasound machine. Duplex machines allow the operator to obtain a B-mode image of the vessel of interest and use this image to position the sample volume gate and adjust the flow angle cursor for Doppler signal collection. Because the same transducer is used for both applications, some ultrasound machines cannot accomplish B-mode and Doppler mode simultaneously. The machine must switch from one operation to the other. During Doppler mode, it is often helpful to periodically update the B-mode image to ensure the sample gate is still correctly positioned in the center of the vessel. The sonographer can adjust the frequency of B-mode image updating from not at all to several times per second.

Doppler Spectral Analysis

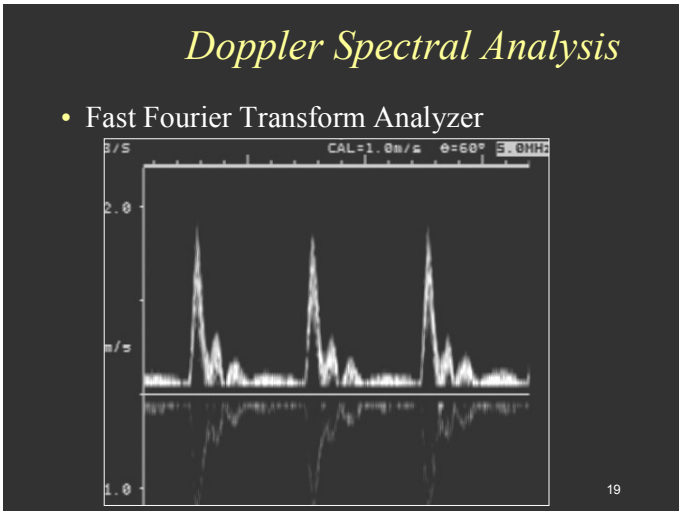
Analysis of the Doppler spectrum can tell us many things about the flow of blood through a vessel, which, in turn, allows us to make deductions about the condition of the vessel itself. Normal blood flow through an average size vessel is described as *laminar*. This means that the fastest flow velocities are found in the middle of the vessel with progressively slower velocities towards the vessel walls. Larger vessels, such as the aorta, exhibit a more blunt velocity profile with less of a difference between flow in the center and flow near the periphery. Vessels with a significant stenosis exhibit a turbulent flow pattern with increased velocity through the open lumen than would normally be seen in the vessel. This velocity increase is caused by the heart trying to pump the same amount of blood through a smaller opening. A device called a Fast Fourier Transform analyzer converts the Doppler signal to a spectral readout with one axis representing Doppler frequency (velocity) and the other representing time.



Spectral Analysis

Spectral window

- The area beneath the peak of the spectral trace is called the *spectral window.*
- Turbulent blood flow can cause fill in of the spectral window, also called spectral broadening.
- Flow above the baseline indicates flow towards the transducer and flow below the baseline indicates flow away from the transducer (unless the image is INVERTED).



Spectral measurements

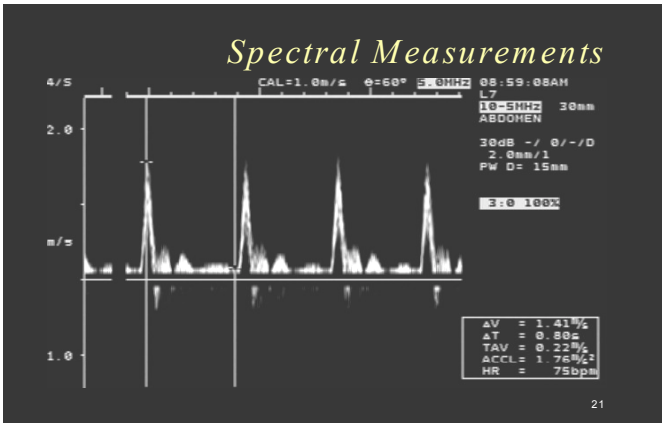
- Max—the maximum (or peak) systolic velocity. An important indicator of vessel stenosis.
- Min—the minimum (or end) diastolic velocity.
- Mean—the average of all velocities at a given moment in time.
- Average—the average velocity throughout the cycle.

There are several calculations that can be made from the measurements listed above that allow physicians to determine circulatory resistance. The amount of resistance present is an important indicator of stenosis.

Pulsatility index— PI = $\frac{\text{(max – min)}}{\text{ave}}$

Resistive index — RI = $\frac{\text{(max – min)}}{\text{max}}$

Systolic/Diastolic Ratio— $\frac{\text{max}}{\text{min}}$



Aliasing and the Nyquist Limit

Sampling—Pulsed Doppler systems (as the name implies) do not continuously record velocity signals, rather they "sample" velocities several times per second. The sampling rate is equal to the pulse repetition frequency (PRF) in Doppler mode.

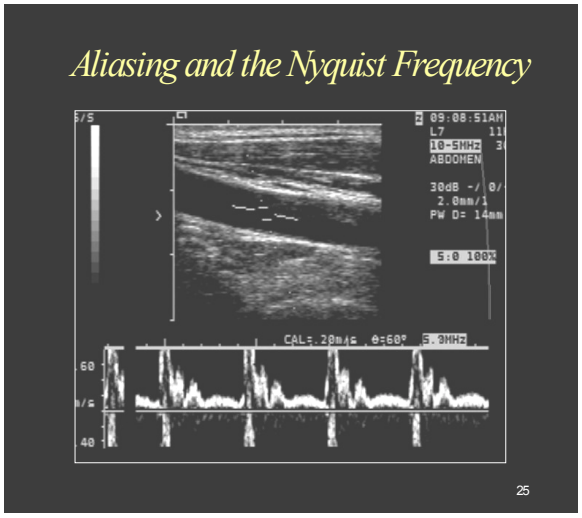
Doppler sampling is analogous to a motion picture film in which a series of still photographs is obtained. When the photographs are viewed in rapid succession, it gives the appearance of live motion. However, if the frame rate during filming is too slow, the motion picture will appear "jerky."

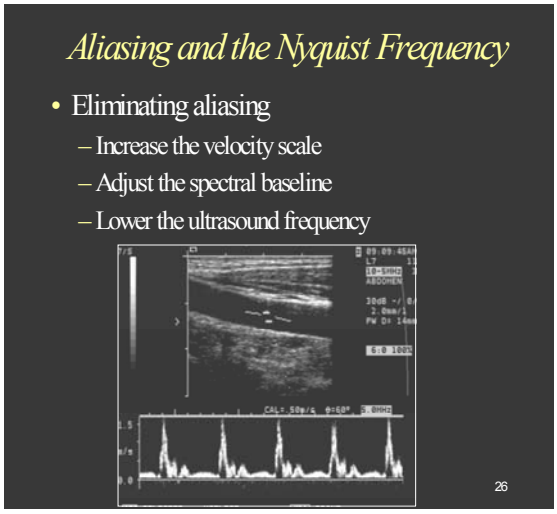
The same sort of thing can happen in Doppler sampling. If the sampling rate (PRF) is too low, it causes false low readings on the spectral display called *aliasing*. To prevent aliasing, the PRF must be at least twice the Doppler frequency. This is called the "Nyquist Limit" Obviously, the Nyquist Limit is dependent on the Doppler frequency, which, in turn, is dependent on the velocity of blood flow. Higher velocity blood flow requires a higher PRF to prevent aliasing.

Eliminating Aliasing

The easiest way to eliminate aliasing is to increase the velocity scale on the spectral display. This will increase the maximum displayable velocity and also increase the PRF of the Doppler sampling. If the velocity scale is at its maximum setting, and there is still

aliasing on the spectral trace, you can sometimes adjust the spectral baseline to eliminate aliasing. Lowering the baseline allows the machine to devote more of the velocity scale to flow above the baseline (towards the transducer) and less to flow below the baseline (away from the transducer). This will allow the scale to show higher velocities in one direction. Finally, lowering the ultrasound frequency can help eliminate aliasing when all else fails because: Lower ultrasound frequencies result in lower frequency Doppler signals for the same velocity. The lower frequency Doppler signals allow us to use a lower PRF even for high velocities.





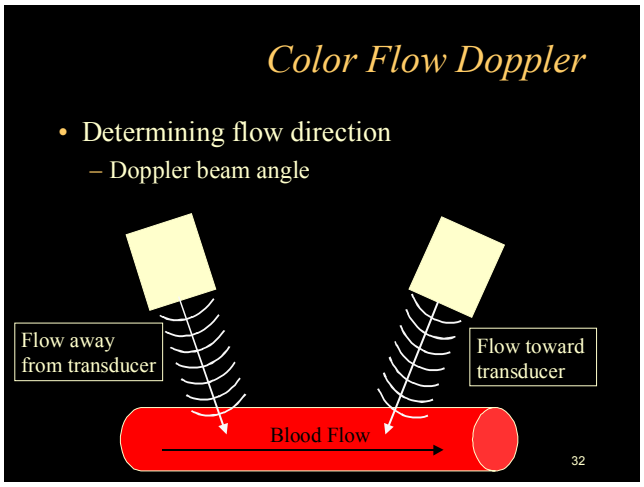
Acoustic Output Levels with Doppler

Be aware that Doppler mode uses a higher PRF than standard B-mode imaging. This results in a higher duty factor (percentage of time sound is actually emitted). In addition, the Doppler beam dwells along a single acoustic line, focusing exposure to a very limited area. These factors combine to produce higher acoustic exposure levels for Doppler ultrasound than for B-mode imaging. To minimize these effects, keep exam times as short as possible and use the lowest power output levels possible.

Color Flow Doppler

Acquiring The Signal

- Collects Doppler signals along multiple beam lines like B-mode.
- Like pulsed doppler, color flow doppler also allows the sonographer to select signals from a specific depth.
- It sends out multiple pulses for each beam line and analyzes the phase of the incoming echoes to detect movement.
- A group of pulses along a single beam line is called a *pulse packet*.
- Echoes received from stationary reflectors are eliminated from the Doppler signal using a *stationary echo-canceling filter*.



Displaying The Signal
The velocities at each depth register are averaged and the mean velocity for that depth is displayed on the screen as a color. Many different color scales can be used, but red and blue are probably the most common. The operator sets the scale so that one color (say red) represents blood flow towards the transducer and the other color (say blue) represents flow away from the transducer. **NOTE:** Red does not *necessarily* represent arterial flow. The degree of brightness, or intensity, of the color represents the velocity of flow at that point.

What do we mean by flow towards the transducer?
Flow direction has to do with the Doppler beam angle. If, for example, the beam is angled caudal when performing a carotid ultrasound, the blood flow in the carotid artery will be toward the transducer. In the aorta, however, the beam should be angled cephalic to display flow toward the transducer. In reality it doesn't matter if arterial flow is toward or away from the transducer, as long as the sonographer understands what a certain color represents in terms of the beam angle and color scale.

Two methods are used to angle the beam with a linear transducer.
Some manufacturers provide an angled offset that fits on the transducer to tilt the transducer while maintaining skin contact. Other manufacturers use beam steering techniques such as those discussed in the section on **Transducer Basics.**

Color Aliasing
- Occurs when flow velocity exceeds the displayed velocity scale.
- Flow appears to be moving in the opposite direction.
- Can be corrected by increasing the displayed velocity scale.
- Can be corrected by increasing the displayed velocity scale.

Doppler Power Mode (Energy Mode)

With Doppler Power Mode, the Doppler signal is processed based on amplitude of received echoes rather than Doppler frequency (velocity). A brighter color is assigned to higher amplitudes rather than faster velocities. Ultimately, the amount of color displayed on the screen relates to the number of blood cells moving in the area rather than the velocity of blood flow.

Advantages of energy mode:

- More sensitive than standard color Doppler
- Flow detection is not angle dependent. Flow is displayed even as the angle approaches 90 degrees.

Disadvantages:

- Flow direction is not displayed.
- Slightly slower frame rates
- Increased flash artifacts from inadvertent patient motion or transducer motion.

Quality Assurance, Artifacts, and Safety

Image Artifacts

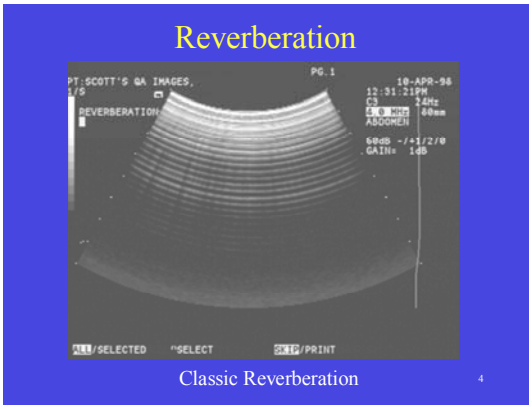
Image artifacts are features that appear on the ultrasound image that don't directly correspond to structures in the object being scanned.

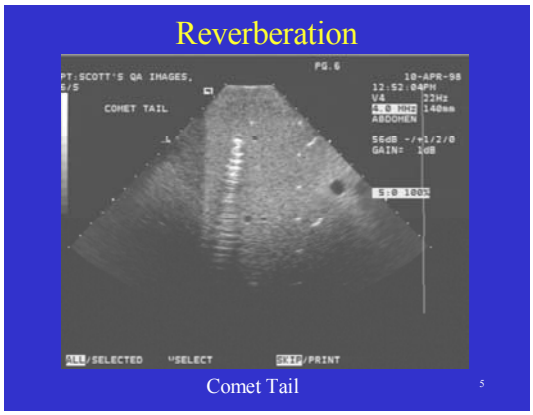
Reverberation—occurs when a strong echo bounces back and forth between interfaces so that it appears multiple times on the image. The artifact appears at regular distance intervals from the original interface and becomes progressively weaker.

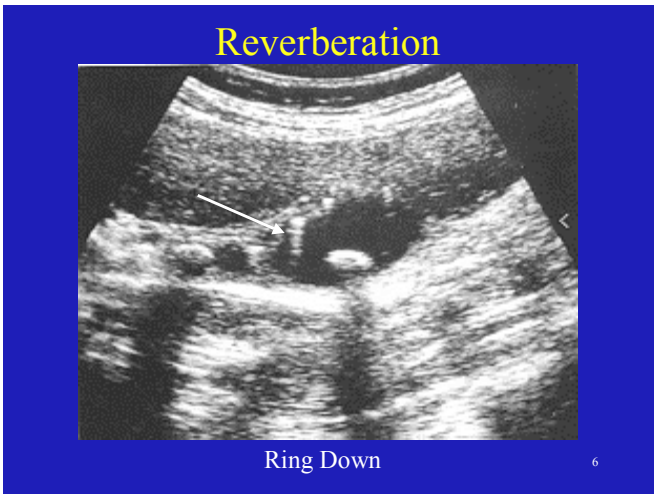
Classic reverberation—occurs between a strong interface (such as the fat–muscle interface in the abdominal wall) and the transducer.

Comet tail—occurs distal to the transducer when the beam encounters a strong reflector such as a metal clip. Sound reverberates within the metal object itself.

Ring-down—occurs at interfaces where small air bubbles or fat globules exist, such as in the diaphragm, bowel, and gall bladder wall.

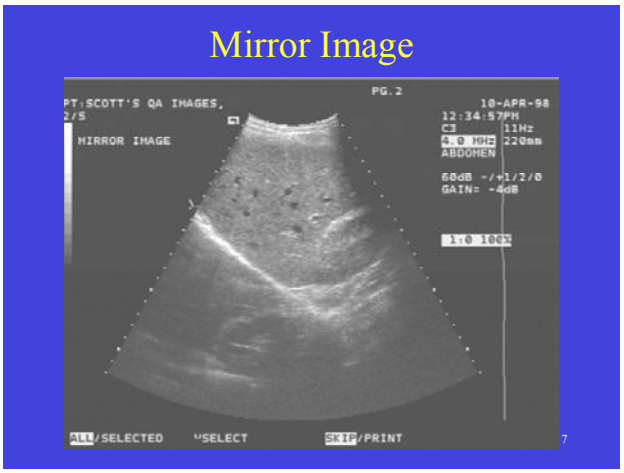






Mirror Image- Similar echo patterns appear both proximal and distal to a very strong reflector, such as the diaphragm or a bony structure.

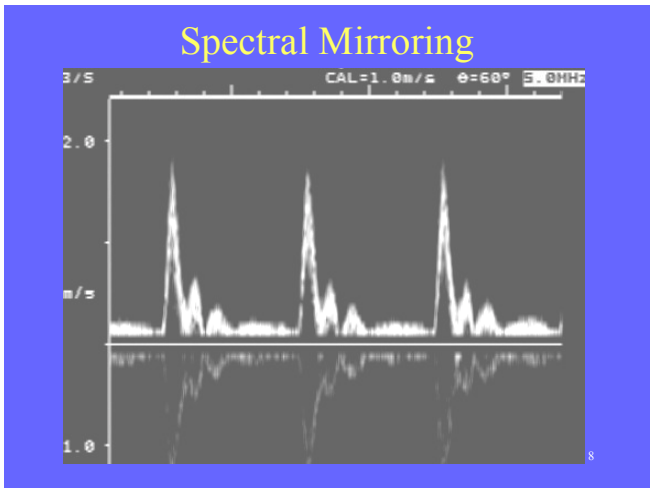
Cause—echoes bounce back and forth between an object and the very strong reflector. The longer echo return time makes the ultrasound machine think that the object has come from a greater distance (beyond the strong reflector).



Spectral Mirroring

Appearance—A reflection of the spectral trace across the baseline.

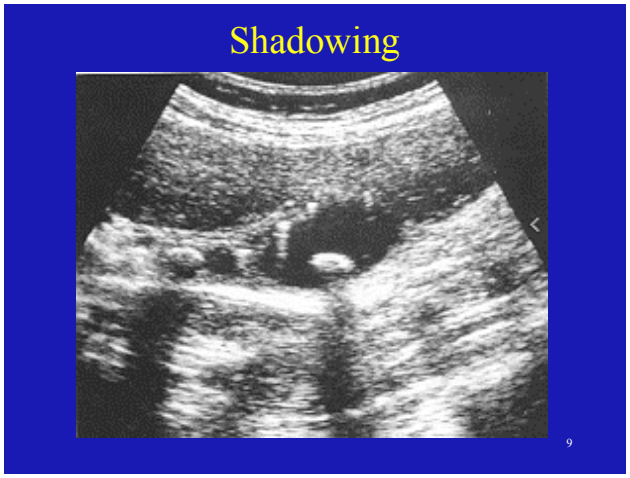
Causes—(1) Doppler gain setting too high, or (2) Doppler angle too steep (too close to 90°).



Shadowing

Appearance—A partial, or complete lack of echo information distal to a strong reflector.

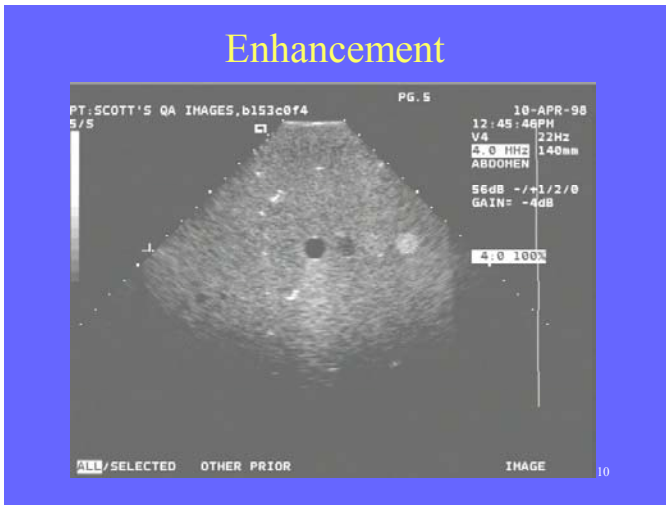
Cause—Any object that has significantly greater attenuation than the surrounding tissue.



Enhancement

Appearance—Opposite of shadowing. Increased amplitude of displayed signals distal to a structure.

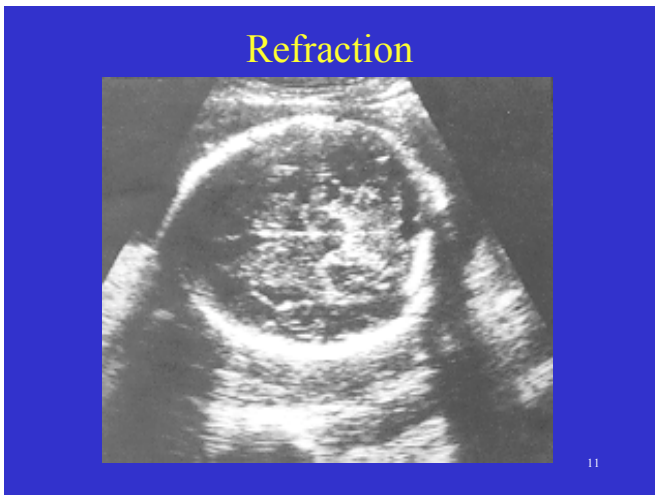
Cause—Any structure with significantly lower attenuation properties than the surrounding tissue (especially fluid filled structures).



Refraction

Appearance—Discontinuity in the echo pattern. Structures appear on the image in locations not corresponding to their actual position within the body.

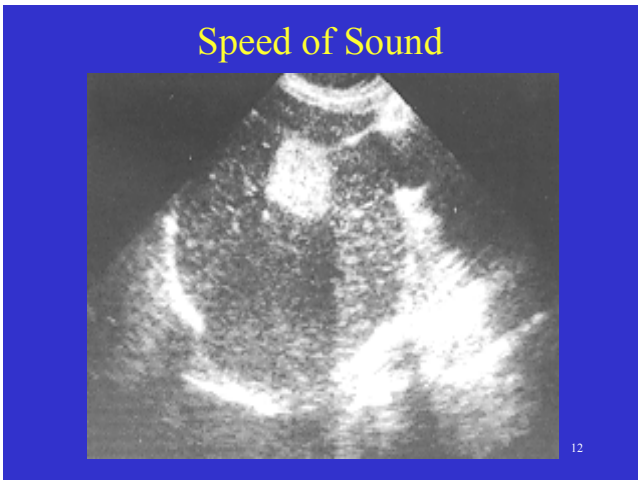
Cause—a nonperpendicular interface in which the speed of sound is different on each side of the interface. Such an interface bends the sound wave.



Speed Of Sound Artifact

Appearance—Structures distal to an object appear closer to or farther from the transducer than they actually are.

Cause—Speed of sound through the given object is different from the average (assumed) speed of sound in soft tissue.



Speed of Sound Artifact

Safety and Bioeffects

Although no damage to biologic tissue has ever been observed as a direct result of *clinical ultrasound imaging*, the potential remains for adverse effects. Research continues in the field of ultrasound exposure. Damage has been demonstrated in laboratory experiments using power settings significantly higher than those used for imaging.

Acoustic Power/Intensity

Power - A measure of the rate of energy transferred into the tissue being scanned.

- Measured in watts
- Typical power level for a B-mode transducer is 10 mW.

Intensity - Takes into account the area of tissue through which the power is distributed.

- It is power per unit area.
- Measured in watts per square centimeter (W/cm^2).

Specifying Acoustical Intensity

Since ultrasound is an alternating waveform energy type, acoustical intensity varies with time. For this reason we must take the time frame into consideration when measuring intensity.

Temporal Peaks And Temporal Averages

Occasionally, we refer to the temporal peak intensity, or I(TP). As the name implies. I(TP) refers to the maximum (or peak) intensity during a single waveform cycle.

More often we refer to temporal average intensity or I(TA). This is the average intensity over a longer time span (say one second). I(TA) increases as the duty

factor increases. (Recall that the duty factor is the percentage of time the transducer is actively pulsing.)

Spatial Peaks And Spatial Averages

- Spatial peak refers to the peak intensity at any point within the ultrasound beam.
- Spatial average refers to the average intensity throughout the beam.

Putting it all together, we have the following possible measurements:

Spatial Average, Temporal Average (SATA) **Spatial Peak, Temporal Average (SPTA)** **Spatial Peak, Temporal Peak (SPTP)**

Mechanisms For Production Of Biological Effects

There are two basic means by which ultrasound can cause changes in biological tissue: thermal and mechanical.

Thermal As sound energy is absorbed by the propagating medium, some of the energy is converted into heat. For low power settings, the amount of heat transferred is quickly dissipated by the body and no measurable temperature change occurs. However, at high power/intensity settings, significant temperature elevation is possible. This is the basis behind ultrasound therapy.

Mechanical This refers to the physical movement and stress placed on tissue due to the vibration from sound waves. There are two types of mechanical effects: **cavitation** and **noncavitation.**

- **Cavitation**—refers to the formation of tiny gas bubbles in the tissue from excessive rarefaction pressure.
- **Noncavitation**—refers to damage caused by the sheer stress of the sound vibration.

Real-Time Acoustical Output Labeling

Current industry standards call for ultrasound manufacturers to quantify acoustic output levels in terms of a thermal index and a mechanical index.

Thermal Index

- A computer estimation of the potential for temperature increase within the exposed tissue at the current machine settings.
- The thermal index represents degrees centigrade.
- It is a worst case estimation and does not necessarily represent actual temperature changes within the tissue.

- May be reported as any of the following depending on specific imaging conditions:
  - **TI**—thermal index
  - **TIC**—thermal index, bone at surface
  - **TIB**—thermal index, bone at focus
  - **TIS**—thermal index, soft tissue at surface
  - **TISF**—thermal index, soft tissue at focus

Mechanical Index

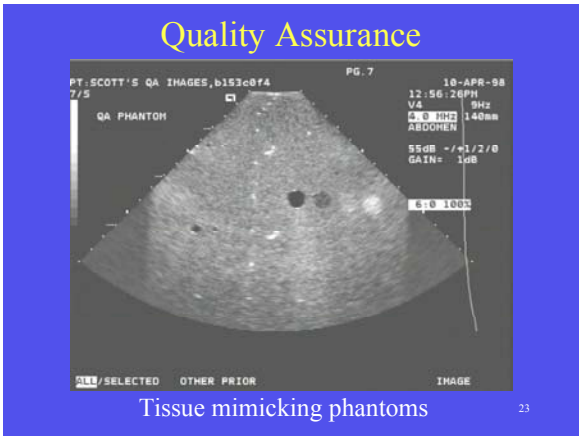
- Relates to the likelihood of cavitation effects produced at current energy settings.
- The sonographer should use these indexes as an aid in practicing ALARA standards and minimizing patient exposure while still obtaining a quality diagnostic examination.

Quality Assurance

Quality assurance means periodically taking steps to ensure ultrasound instruments are operating consistently at their expected level of performance.

Tissue Mimicking Phantoms

- Composed of water based gel/graphite material that mimics speed and attenuation properties of sound in soft tissue.
- Contain various types of reflectors including simulated cysts for testing contrast resolution and nylon lines placed at specific intervals for testing spatial resolution and measurement accuracy.
- Used to perform a variety of QA tests, such as the ones listed below.



NOTE: For standardization purposes and to facilitate accurate comparisons of system performance over time, the following tests should be performed with the same transducer each time. It is generally recommended that you select the transducer most frequently used during clinical imaging.

Depth Of Penetration

- Purpose—to determine the maximum depth from which useful echoes can be visualized.
- Procedure
  - Set the output power to maximum.
  - Increase the gain setting to the highest setting without excessive noise.
  - Increase the image depth until the useful echo signals fade to black.
  - Measure and record the maximum depth of visualization.
  - Record all instrument settings for use on subsequent tests.

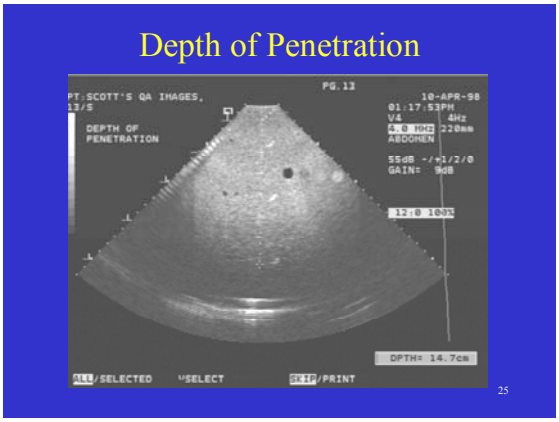
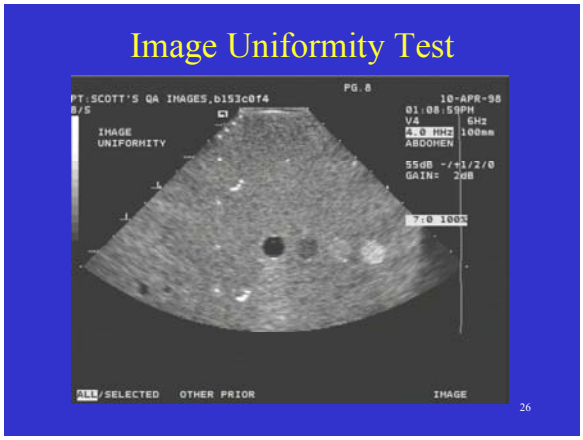
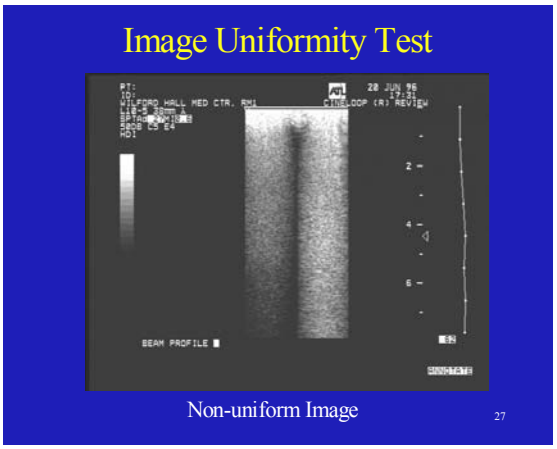


Image Uniformity

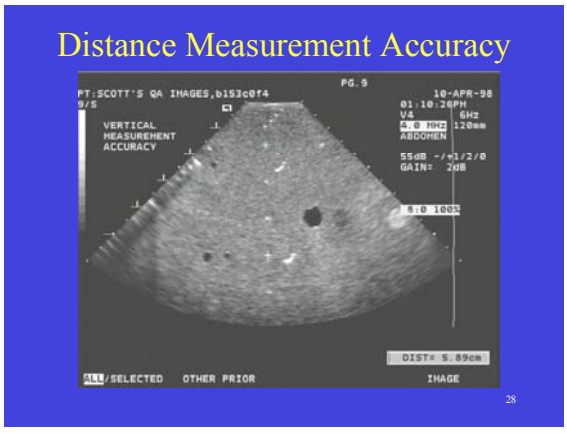
- Purpose—to check for uniform brightness and contrast throughout the image field.
- Procedure
  - Adjust imaging depth, focal zones, output power, and gain settings to produce an optimal image. Record setting for future use.
  - Scan a portion of the phantom with the fewest targets.
  - Check for non-uniformities such as vertical or horizontal lines or a loss of echo signals localized to one area of the image.

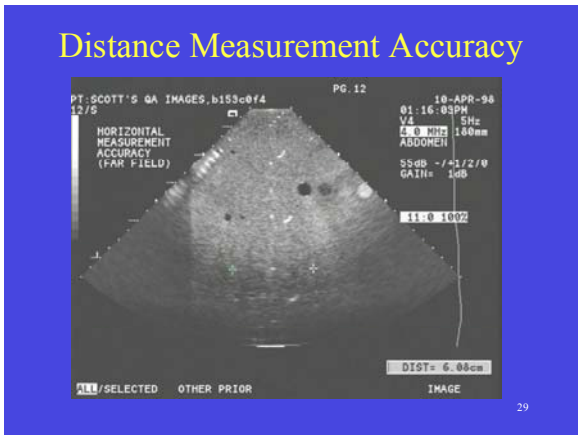




Distance Measurement Accuracy

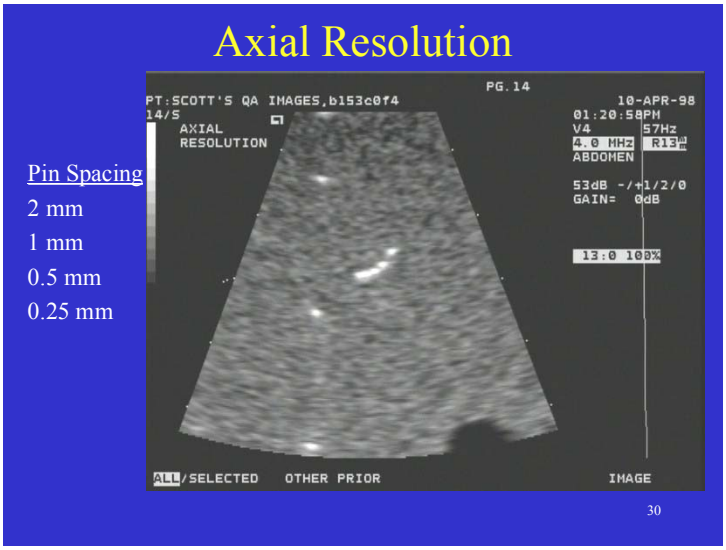
- Purpose—to test the accuracy of the system measurement calipers.
- Procedures
  - Adjust imaging depth, focal zones, output power, and gain settings to produce an optimal image. Record setting for future use.
    - Vertical
      - Scan the vertical column of pin targets.
      - Freeze the image and measure the distance between selected pins (for instance between the pins at depths 2 and 12 cm).
      - Record the measured distance.
    - Horizontal
      - Scan the row of pins nearest the transducer.
      - Freeze the image and measure the distance between selected pins.
      - Record the measured distance.
      - Repeat for the row of pins farthest from the transducer.





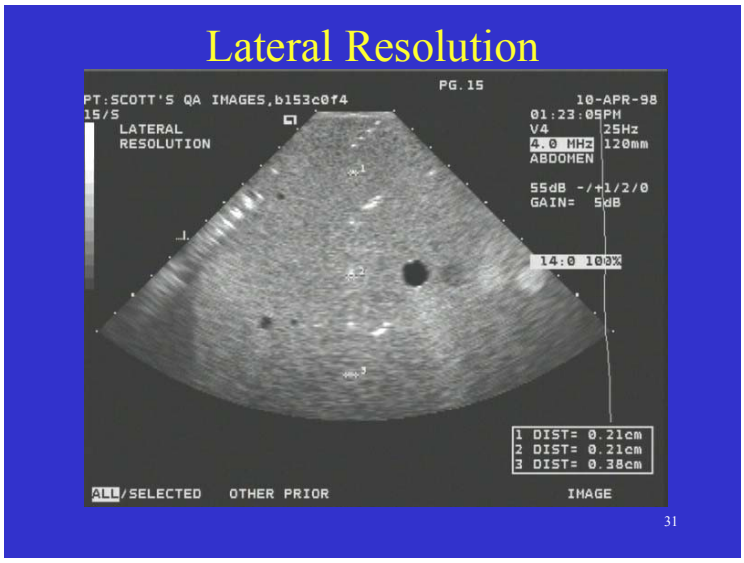
Axial Resolution

- Purpose—To measure the system's ability to resolve closely spaced objects along the beam path.
- Procedure—There are three groups of axial resolution targets at different depths in the phantom. Pin spacings from top to bottom within the group are 2 mm, 1 mm, 0.5 mm, and 0.25 mm. The test should be performed on all three groups.
    - Adjust imaging depth, focal zones, output power, and gain settings to produce an optimal image. Record setting for future use.
    - Scan the target group.
    - Freeze the image and determine the two pins with the smallest vertical spacing that do not overlap.
    - Record findings and repeat for the other two groups of pins.



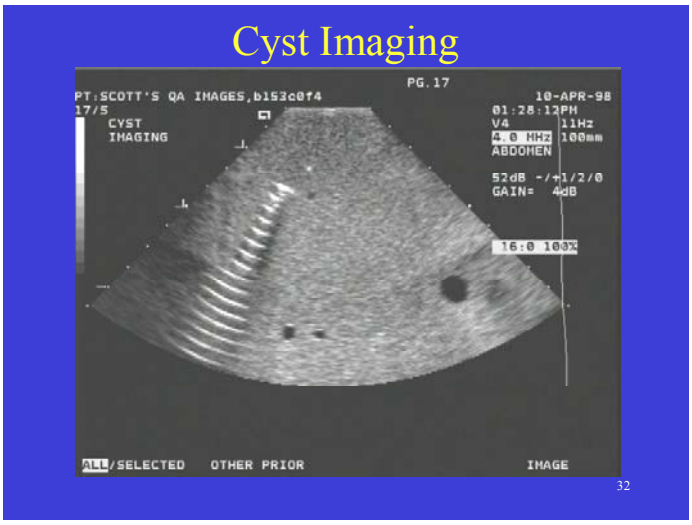
Lateral Resolution

- Purpose—to test the system's ability to distinguish small, adjacent structures perpendicular to the beam path.
- Procedure
    - Adjust imaging depth, focal zones, output power, and gain settings to produce an optimal image. Record setting for future use.
    - Scan the vertical column of pin targets with a single focal zone in the middle of the image depth.
    - Freeze the image and measure the width of three pins: one from the near field, one from the focal zone, and one from the far field.
    - Record measurements.



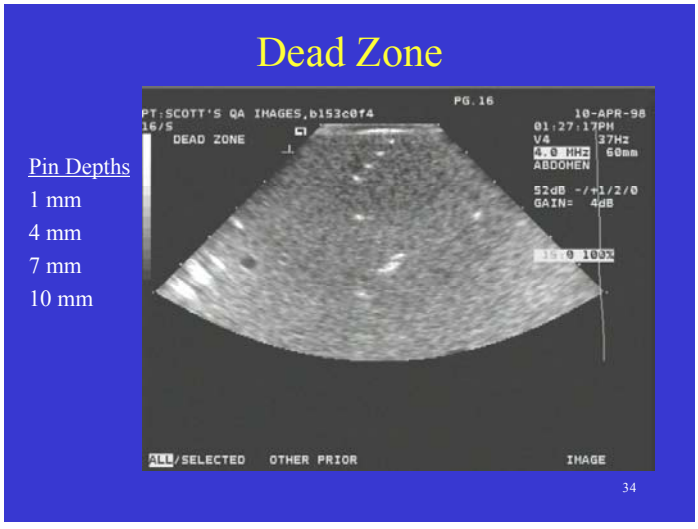
Cyst Imaging

- Purpose—To test the system's ability to display round, negative contrast objects.
- Procedure—There are three groups of cysts positioned at different depths in the phantom. The test should be performed on each of the groups.
  - Adjust imaging depth, focal zones, output power, and gain settings to produce an optimal image. Record setting for future use.
  - Obtain an image of the target group.
  - Rate the largest cyst on the following characteristics. (**NOTE:** Use a rating scale of 1 to 3 with "1" being optimal and "3" being poor.)
    - Shape: Height and width measurements should be equal.
    - Edge: The edge of the cyst should be sharply defined.
    - Texture: The interior of the cyst should be echo free.
  - Determine the smallest visible cyst at near, mid and far depths.
  - Record findings.

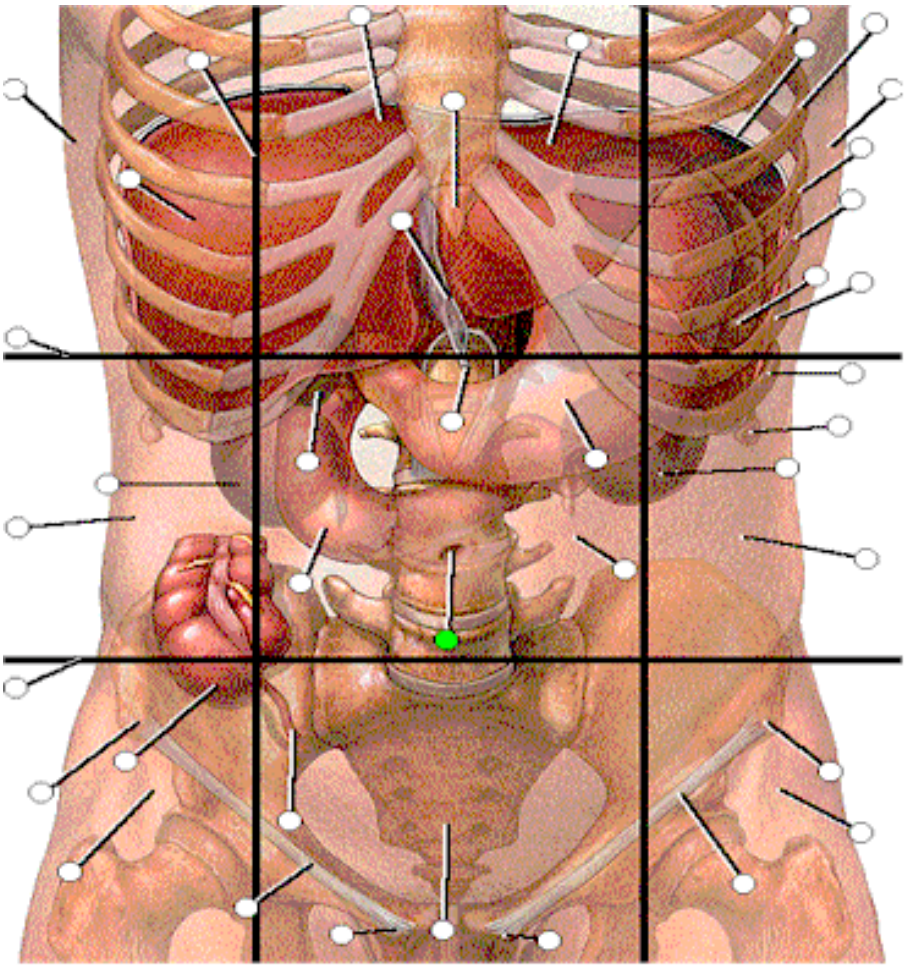


Dead Zone

- Purpose—To measure the width of the image "dead zone" (the portion of the image directly below the transducer where image detail is missing).
- Procedure
  - Adjust imaging depth, focal zones, output power, and gain settings to produce an optimal image. Record setting for future use.
  - Scan the dead zone target group.
  - Determine the depth of the closest pin which can be imaged. (The pin depths are 1, 4, 7, and 10 millimeters.)
  - Record findings



ABDOMINAL ANATOMY AND PHYSIOLOGY



ABDOMINAL ANATOMY AND PHYSIOLOGY

LIVER

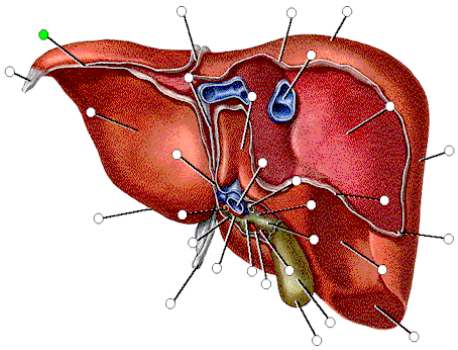
Physiology– The liver is the primary center of metabolism that supports multiple body systems and aids in digestion. It has three primary functions; body system metabolism, detoxification, and storage.

- Metabolism– The liver supports the digestive & excretory system by metabolizing fat, carbohydrates, proteins, and forms bile and urea.
  - *1)* <u>*Carbohydrate*</u> <u>*metabolism*</u>– serves as a major site for conversion of dietary sugars into glucose. Excess glucose is converted into glycogen (a starch) for storage.
  - *2)* <u>*Protein*</u> <u>*metabolism*</u>– converts amino acids and other compounds into the following blood proteins: albumen, fibrinogen, and prothrombin.
  - *3)* <u>*Fat*</u> <u>*metabolism*</u>*-d*ietary fats are converted to lipoproteins that are transported throughout the body where they are used by other organs or stored. Stored fats may be transported to the liver and converted into energy yielding glucose and other substances such as cholesterol.
  - **NOTE:** Cholesterol is a major component of bile, which serves to emulsify fats during digestion
- *Storage*– stores vitamins, minerals, and other metabolic substances for later use
- *Detoxification*– breaks down harmful chemicals, hormones, aging blood cells, and bacteria.

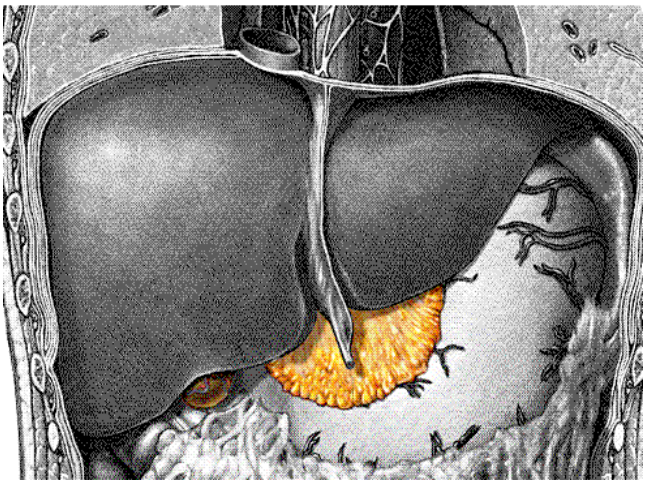
Size: varies with patient and body habitus. Male– weighs between 1400 & 1800 grams. Female– weighs between 1200 & 1400 grams. Right lobe larger than the left lobe and contains approximately 2/3's of the parenchymal tissue the superior-inferior measurement is taken along the midclavicular line in a longitudinal plane from the tip of the liver to the diaphragm. Normal superior-inferior measurement is approximately less than or equal to 15 cm. **Note:** Hepatomegaly is present when the liver measurement exceeds 20 cm. Left lobe is more varied in size; measurement of the left lobe is not performed.

Location– The liver occupies a major portion of the right hypochondrium and normally extends into the epigastrium and the left hypochondrium. *Right l*obe– occupies the right hypochondrium. *Left lobe*– lies in the epigastric and left hypochondrium regions. *Caudate lobe*– The smallest lobe, is situated on the posterior surface of liver lying between the fossa of the IVC and the fissure ligamentum venosum.

Relational Anatomy- *Stomach*– The fundus lies posterior and lateral to the left lobe of the liver and may be frequently seen on transverse sonograms. The remainder of the stomach lies inferior to the liver. *Duodenum*– lies adjacent to the right lobe and medial segment of the left lobe of the liver. *Pancreas*– usually seen just inferior to the liver. *Other structures*– The posterior border of the liver contacts the right kidney, IVC, and aorta. *Diaphragm*– covers the superior border of the liver.



Gross Anatomy/Sonographic appearance– The liver is composed of the right, left, and caudate lobes, the vasculature, peritoneal covering, and ligament attachments.
Note: The liver should be homogeneous and moderately echogenic throughout.
Right lobe – is the largest portion of the liver. *Gallbladder fossa*– is on the posterior surface of the right lobe that contains the gallbladder. *Subhepatic space (Morrison's pouch)* – is the space between the anterior surface of the kidney and the posterior surface of the right lobe. ***Left lobe****-Intersegmental fissure*– divides the medial and lateral segments of the left hepatic lobe. It contains the falciform ligament and ligamentum teres. *Quadrate lobe*– is not an anatomically distinct lobe, but is more correctly identified as the medial segment of the left lobe. ***Caudate lobe-*** It is a midline structure on the posterior aspect of the liver and separates a portion of each of the right and left hepatic lobes. The proximal portion of the left hepatic vein and the fissure of the ligamentum venosum separate it from the left lobe.



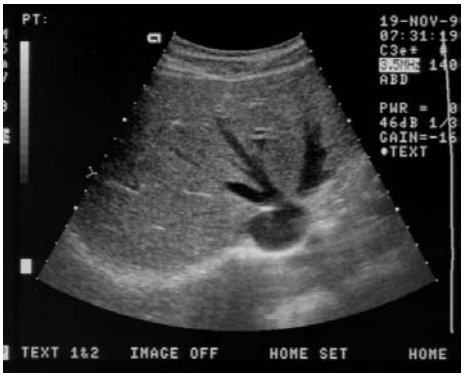
Liver surface covering: ***Glisson's capsule***– is a tight fibrous capsule that encloses the liver and is largely covered by the peritoneum. The ***Bare area*** is the portion of the posterior surface of the liver without any peritoneal covering. This portion is in direct contact with the diaphragm. ***Peritoneal ligaments***– connect the liver to upper abdominal structures. ***Coronary ligament***– connects the posteriosuperior surface of the liver to the diaphragm at the margins of the bare area
Falciform ligament- connects the liver to the anterior abdominal wall and to the diaphragm. It divides left lobe of the liver into medial and lateral segments. It is highly

echogenic on both longitudinal and transverse scans. It appears sickle shaped on longitudinal scans and pyramidal on transverse scans. Can be difficult to distinguish from the ligamentum teres. ***Ligamentum venosum-*** separates the left lobe from the caudate lobe. It is the remnant of the ductus venosus, which shunted oxygenated blood from the umbilical vein to the inferior vena cava (IVC). ***Round ligament*** **(ligamentum teres)**– is the obliterated umbilical vein, a fibrous cord which extends upward from the diaphragm to the anterior abdominal wall. It runs parallel to the falciform ligament.

Liver vasculature: Hepatic veins– appear as sonolucent structures with anechoic borders.

- *Right hepatic vein*– separates and drains anterior and posterior segments of the right lobe.
- *Middle hepatic vein*– separates and drains the right lobe and the medial segment of the left lobe.
- *Left hepatic vein*– separates and drains the medial and lateral segments of the left lobe.

The hepatic veins subdivide into superior and inferior groups. The smaller inferior veins drain the caudate lobe and the posteromedial portion of the right lobe. ***Portal venous system-*** supplies 75 percent of total blood flow to the liver. *Porta hepatis*– is the transverse fissure of the liver through which the portal vein and hepatic artery enter and through which the hepatic ducts exit. **Hepatic artery proper**– feeds the liver with oxygenated blood.



To distinguish sonographically portal veins from hepatic veins: Portal veins– appear as bright walled sonolucent structures. Hepatic veins– can be distinguished from portal veins by their sonographic location and appearance. Hepatic veins course between the hepatic lobes and segments; the major portal branches course within the lobar segments. Hepatic veins drain toward the right atrium; the portal veins emanate from the porta hepatis. Terms used to reference the flow within the hepatic venous system are: *Hepatofugal* – flow away from the liver. *Hepatopetal* – flow towards the liver. **Normal variants**– Reidel's lobe– a tongue-like inferior extension of the right lobe extending as far caudally as the iliac crest

Sonographic Applications: Indications– examinations of the liver are indicated but not limited to the following: Suspected liver enlargement, hepatic or perihepatic masses, abscesses, obstructive or metastatic lesions, cystic, solid, and complex masses are readily identified because they distort the smooth contour of the liver. Abnormal lesions usually

are increased or decreased in echogenicity when compared to the moderate echo strength of the liver. *Pleural effusions*– are seen in the supradiaphragmatic region superior to the liver. *Ascites*– is seen as fluid collections in the subcapsular or intraperitoneal spaces surrounding the liver.

Vascular applications (color & pulsed wave doppler) - used for detecting the presence, direction, and sample volume velocity of blood vessels within the liver. The portal vein, the hepatic arteries and veins, and the splenic artery & vein are the primary vessels evaluated during a liver sonogram.

LIVER FUNCTION TESTS

Defined as a group of laboratory tests established to analyze how the liver is performing under normal conditions. **Aspartate aminotransferase (AST formerly SGOT)** Aspartate aminotransferase is an enzyme present in tissues that have a high rate of metabolic activity, one of which is the liver. As a result of death or injury to the liver cells, the enzyme is released into the blood stream at in abnormally high levels. Any disease that injures the cells causes an elevation in AST levels. This enzyme is also produced in other high-metabolic tissues, so an elevation does not always mean liver disease is present. Significant elevations are characteristic of acute hepatitis and cirrhosis. **Alanine aminotransferase (ALT, formerly SGPT)** Alanine aminotransferase is more specific than AST for evaluating liver function. There is mild to moderately elevated enzyme levels in obstructive jaundice and moderate to high levels in hepatocellular disease and infectious or toxic hepatitis. **Alkaline phosphatase (Alk Phos) -** is produced by the liver, bone, intestines, and placenta. It is a good indicator for the following: Intrahepatic or extrahepatic obstruction Hepatic carcinoma, Abscess, Cirrhosis. **Bilirubin (indirect, direct)** - is the product of the breakdown of hemoglobin in tired red blood cells. The liver converts these byproducts into bile pigments that with other factors are secreted as bile into the bile ducts. The bile production cycle can be disturbed by the following problems: An excess amount of red blood cell destruction, malfunctioning liver cells, blockage of the bile duct system. Disturbances in the bile production cycle cause a rise in serum bilirubin, which leaks into the tissues and thus gives the skin jaundice, or yellow coloration. There are two types of bilirubin tests, indirect (unconjugated) bilirubin and direct (conjugated) bilirubin. Elevated *direct bilirubin* is usually the result of obstructive jaundice (from stones or neoplasm). Elevated *indirect bilirubin* is seen with red blood cell destruction (anemia's, hematoma from a trauma, or hemorrhagic pulmonary infarct). **Prothrombin time** - is a liver enzyme that is part of the blood clotting mechanism. Its production depends on adequate intake and use of vitamin K. The prothrombin time is increased in the presence of liver disease with cellular damage. Cirrhosis and metastatic disease are examples of disorders that cause prolonged prothrombin time.

Diffuse disease

Diffuse hepatocellular disease both affect the hepatocytes and interfere with liver function.

Hepatocyte: The hepatocyte is a parenchymal liver cell that performs all the functions ascribed to the liver. Any hepatocyte abnormality can be measured through the series of

liver function tests. Liver function tests are specific to diffuse disease. Hepatic enzyme levels are elevated with cell necrosis. With cholestasis the alkaline phosphatase and direct bilirubin levels increase. There are many subcategorizes of diffuse parenchymal disease, the most common are: *fatty infiltration, acute and chronic hepatitis, early alcoholic liver disease, and acute and chronic cirrhosis*.

Fatty infiltration: Defined – It is the abnormal accumulation of fat droplets in the cytoplasm of liver cells and results from significant injury to the liver or a systemic disorder leading to impaired or excessive metabolism of fat. Results from accumulation of fat exceeding the normal 5% of liver weight. It is a benign process and may be reversible. Common causes are *alcoholic liver disease, diabetes mellitus, obesity, severe hepatitis, chronic illness, and steroids.* There are three grades of liver texture that have been defined in sonography for classifications of fatty infiltration, *grades 1, 2, and 3*.
Grade 1- (mild) demonstrates a slight diffuse increase in fine echoes in the hepatic parenchyma with normal visualization of the diaphragm and intrahepatic vessel borders.
Grade 2– (moderate) shows a moderate diffuse increase in fine echoes with a slightly impaired visualization of the intrahepatic vessels and diaphragm.
Grade 3–(severe) demonstrates a marked increase in fine echoes with poor or no visualization of the intrahepatic vessel borders, diaphragm, and posterior portion of the right lobe of the liver.

Non-uniform fatty infiltration It is not uncommon to see patchy distribution of fat, especially in the right lobe of the liver. An important sonographic consideration is that fat does not displace normal vascular architecture.

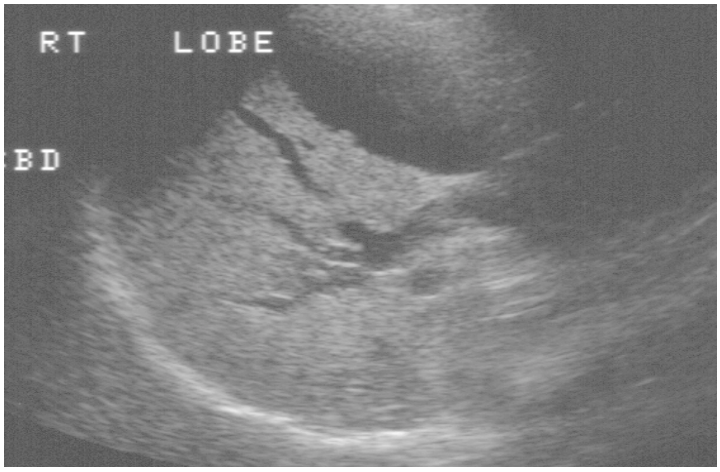
Focal sparing: A diffusely fatty liver may have small areas of normal parenchyma spared by fatty infiltration. Cause is unclear, but may be related to decreased regional portal flow. The most common sites for this condition are located in the medial segment of the left lobe adjacent to the main lobar fissure, anterior to the portal vein bifurcation, or medial and anterior to the neck of the gallbladder.

Hepatitis: is defined as general inflammation of the liver, usually from a viral infection, but sometimes from toxic agents. In the US, about 60 % of acute viral hepatitis is type B, and about 20% is type non-A, non-B. Type A is transmitted by the fecal-oral route and type B is transmitted through a chronic carrier or via a parenteral inoculation (similar to the AIDS virus). Clinical symptoms: Patients may initially present with flu and GI symptoms, including a loss of appetite, nausea, vomiting and fatigue. Jaundice may occur in severe cases. Lab values– show abnormal liver function tests with increases in the AST, ALT, and bilirubin.

Acute hepatitis: Damage to the liver may range from mild disease to massive necrosis and liver failure. **Sonographic findings:** portal vein borders are more prominent than usual. Liver parenchyma may be equal to or slightly less echogenic than normal. Hepatosplenomegaly is present and the gallbladder wall is thickened.
Chronic hepatitis: This condition exists when there is clinical or biochemical evidence of hepatic inflammation for at least 3 to 6 months. There are two types of chronic

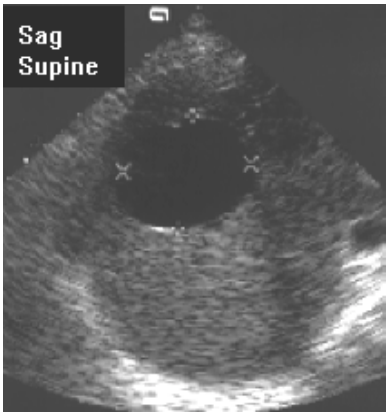
hepatitis 1) *Chronic persistent hepatitis*– is a benign self-limiting process. 2) Chronic active hepatitis– usually progresses to cirrhosis or liver failure. **Sonographic findings:** the liver parenchyma is coarse with decreased brightness of the portal triads, but the degree of attenuation is not as great as fatty infiltration. The liver does not increase in size with chronic hepatitis. Fibrosis may be evident, which is "soft shadowing" posteriorly.

Cirrhosis: It is a chronic disease of the liver caused by parenchymal necrosis, scaring, fibrosis, and regeneration resulting in disorganization of the hepatic lobular and vascular architecture. Alcoholism accounts for 60% to 70% of all cases of cirrhosis in the western world, whereas in Asia and Africa, viral hepatitis is the usual cause. The disease process is chronic and progressive and with liver cell failure and portal hypertension in the end stage. Clinical symptoms are nausea, flatulence, anorexia, weight loss, ascites, light-colored stools, weakness, abdominal pain, varicosities and spider angiomas. Ultrasound findings may be difficult to diagnose with ultrasound, specific findings may include: increased echogenicity, increased attenuation, decreased vascular markings, hepatosplenomegaly with acute: shrunken liver size with chronic Ascites, nodularity or regenerating nodules, and portal hypertension.



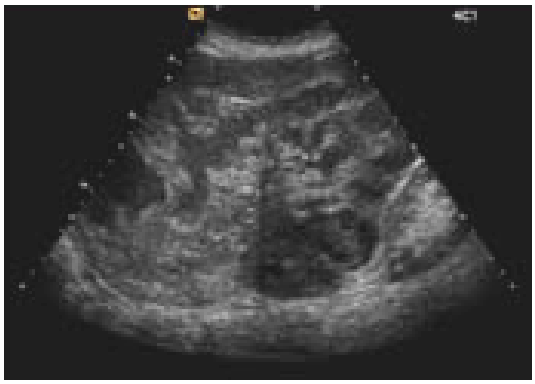
Biliary obstruction:
Obstruction proximal to the cystic duct causes carcinoma of the CBD or metastatic invasion of the porta hepatis. Clinical symptoms– the patient may be jaundiced with pruritus (itching). Lab tests– Liver function tests show an elevation in direct bilirubin and alkaline phosphatase levels. **Sonographic findings:** Carcinoma of the common duct shows a tubular branching with dilated intrahepatic ducts best seen in the periphery of the liver. **Note:** It may be difficult to image a discrete mass lesion. The gallbladder may be contracted. Obstruction distal to the cystic duct: Causes - It may be caused by stones in the common duct, an extrahepatic mass in the porta hepatis, or stricture of the common duct. Clinical symptoms – RUQ pain, jaundice, and pruritus. Lab values– Increased direct bilirubin and alkaline phosphatase levels. **Sonographic appearance:** Dilated intrahepatic ducts in the periphery of the liver. Gallstones are often present and appear as hyperechoic lesions along the posterior floor of the gallbladder.

Cystic lesions Hepatic cysts may be congenital or acquired, solitary or multiple. Simple hepatic cysts are frequent incidental findings during hepatic sonography, with an incidence of 2.5%to 4.6% of the population. Patients are often asymptomatic, except patients who have large cysts, which can compress the hepatic vascular or ductal system.



Simple hepatic cysts occur more often in females than males. If the cyst grows, it may cause pain or mass effect to suggest a more serious condition, such as infection, abscess, or necrotic lesion. **Sonographic appearance:** they have thin walls with well-defined borders, and are anechoic with distal posterior enhancement.

Polycystic liver disease - It is autosomal-dominant and affects one person in 500. At least 20% to 50% of patients with polycystic renal disease have one or more hepatic cysts. Of the patients with polycystic liver disease, 60% have associated polycystic renal disease. **Sonographic appearance:** Histologically, they possess the same characteristics as a simple cyst. The cysts are small, under 2 to 3 cm, and multiple throughout the liver parenchyma. Cysts within the porta hepatis may enlarge and cause biliary obstruction. It may be difficult to assess formation of a neoplastic lesion in a patient with polycystic liver disease.



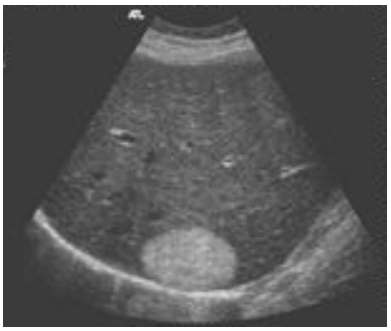
Inflammatory hepatic lesions: Hepatic abscesses occur most often as complications of biliary tract disease, surgery, or trauma. There are three basic types, intrahepatic, subhepatic, and subphrenic. Clinical symptoms include fever, elevated white cell counts, and RUQ pain. Sonographic evaluation: The search for an abscess must be made to locate solitary or multiple lesions within the liver or to search for

abnormal fluid collections in Morison's pouch, in the subdiaphragmatic or subphrenic space.

Pyogenic abscess: It is a "pus-forming" abscess formation. It is caused by bacteria introduced into the body through a direct extension from a contiguous infection, and rarely, through hepatic trauma. **Note:** The most frequent sources are *E. coli* and *anaerobes*. Clinical symptoms are fever, pain, pleuritis, nausea, vomiting, and diarrhea. Lab tests– Elevated liver function tests, leukocytosis, and anemia are present. Abscesses are multiple in 50% to 67% of patients. **Sonographic appearance:** may be variable depending on the internal consistency of the mass. The size varies from 1 cm to very large. The right central lobe is the most common site for abscess development. The abscess may be hypoechoic with round ovoid margins and acoustic enhancement or it may be complex with debris along the posterior margin and irregular walls. It may have a fluid level; if gas is present, it can be hyperechoic with dirty shadowing.

Hepatic tumors:

Neoplasm is defined as any new growth of tissue, either benign or malignant. A *benign growth* occurs locally but does not spread or invade surrounding structures. It may push surrounding structures or adhere to them. A *malignant mass* is uncontrolled and is prone to metastasize to nearby or distant structures via the blood stream or lymph nodes. **NOTE:** There are many different types of tumors. Only the most common pathology will be discussed.



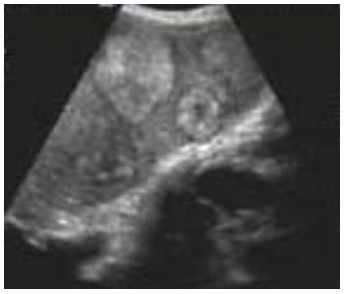
Benign tumors:

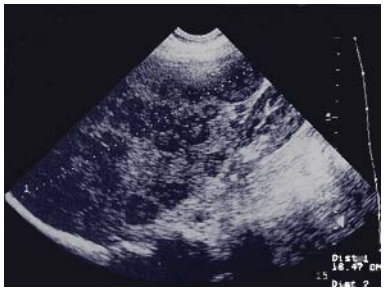
Cavernous hemangioma: It is the most common benign tumor of the liver. It is a benign, congenital tumor consisting of large, blood-filled cystic spaces. It is found more frequently in females. Clinical symptoms: Patients are usually asymptomatic although a small percentage may bleed, causing RUQ pain. They enlarge slowly and undergo degeneration, fibrosis, and calcification. **Sonographic appearance:** is hyperechoic with acoustic enhancement. They are round, oval, or lobulated with well defined borders. They may become more heterogeneous as they undergo degeneration and fibrous replacement. Atypical hemangiomas may also project with calcifications, complex, or anechoic echo pattern.

Focal nodular hyperplasia: The lesion is composed of normal hepatocytes, Kupffer's cells, bile duct elements, and fibrous connective tissue. It's found in younger women under the age of 40. An increased incidence is seen on women using oral contraceptive pills, and there is an increased bleeding within the tumors of these patients. The patient is

asymptomatic. The lesions occur more in the right liver lobe and may be solitary or multiple. The lesions appear as a solid mass of variable size and echogenicity. The tumors often measure less than 3 cm although lesions up to 20 cm have been reported. With color doppler sonography in addition to peripheral flow, centrifugal arterial flow originating from central portion of the tumor and in some cases, radiating peripherally from a central vessel in a stellate configuration.

Malignant tumors:
Hepatocellular carcinoma: The pathogenesis of hepatocellular carcinoma is related to cirrhosis, chronic hepatitis B virus infection, and hepatocarcinogens in foods. **Note:** 80% of patients with cirrhosis develop hepatocellular carcinoma. The tumor comprises 90% of all primary hepatic malignancies. **Note:** It also occurs more frequently in men. The carcinoma may be present in one of three patterns: *solitary massive tumor, multiple nodules throughout the liver, or diffuse infiltrative masses in the liver.* **Note:** All of the patterns cause hepatomegaly. The mass can be invasive and has been known to invade the hepatic veins to produce Budd-Chiari syndrome. **Note:** The portal venous system may also be invaded with tumor or thrombosis. **Clinical symptoms:** Palpable mass in the liver hepatomegaly, unexplained fever, signs of cirrhosis. **Labs:** Hepatocellular carcinoma produces no abnormalities in liver function tests other than indications of cirrhosis. **Sonographic findings:** A variable appearance is noted with discrete lesions, either solitary or multiple, which are usually hyperechoic or hypoechoic. Another pattern presents as diffuse parenchymal involvement with inhomogeneity throughout the liver without distinct masses. The last pattern is a combination of discrete and diffuse echoes. **Note:** The sonographer cannot differentiate hepatocellular carcinoma from metastases on ultrasound due to their identical appearance.





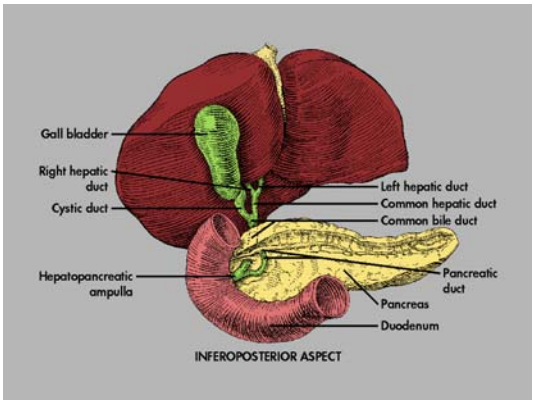
Metastatic disease: It is the most common form of neoplastic involvement of the liver. Metastases are 18 to 20 times more common than primary malignant tumors. The primary sites are colon, breast, and lung. **Note:** The majority of metastases arise from a primary colonic malignancy or a hepatoma. Clinical symptoms: Hepatomegaly, Abnormal liver function tests, Weight loss and decreased appetite. **Ultrasound findings:** The ultrasound findings are very similar to hepatocellular carcinoma. Target types of metastases or bull's-eye patterns are the result of edema around the tumor or necrosis, or hemorrhage within the tumor.

Hepatic Vascular Flow Abnormalities:
Portal venous hypertension: Defined as the development of increased pressure in the portal venous system, which could be caused by thrombus, diffuse disease, or tumor

invasion. **Note:** This usually results in restricted or reversed flow of the portal venous system. The most common mechanism for increased resistance to flow occurs in patients with cirrhosis. Collateral circulation develops when the portal venous channels become obstructed. This diverted blood flow causes hepatofugal blood flow as the blood becomes diverted into collateral vessels. **Note:** The most common collateral pathways are the coronary and esophageal veins (80% to 90%). Color Doppler evaluation: the most important vessels to document flow in the suspected portal venous hypertensive patient is the right, left, main portal vein, hepatic veins, and the IVC.

Budd-Chiari syndrome: It is an uncommon, often dramatic illness caused by thrombosis of the hepatic veins or IVC. It has a poor prognosis. Extensive hepatic vein occlusion is usually fatal within weeks or months of the onset of symptoms. It is classified as *primary* or *secondary* on the basis of its pathological cause.
Primary - It is caused by congenital obstruction of the hepatic veins or the IVC by membranous webs across the upper IVC at or just above the left and middle hepatic veins. This form of lesion is found to be most common in Asia.
Secondary thrombosis - results from thrombosis in the hepatic veins or IVC. It often occurs in patients with predisposing conditions such as: prolonged use of oral contraceptives, tumors, and in rare cases, trauma. **Clinical manifestations:** Ascites is the most characteristic clinical feature of this disease. Other symptoms include: abdominal pain, hepatomegaly, jaundice, vomiting, and diarrhea. This condition often occurs in patients with an underlying disease, such as renal cell carcinoma or primary liver cancer. **Ultrasound findings:** The presence of ascites, absent blood flow in the hepatic veins or the IVC, which should be documented with color and pulse wave Doppler.

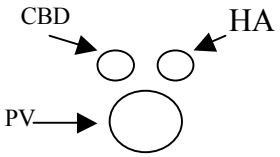
GALLBLADDER AND BILIARY SYSTEM:



Physiology: The primary function of the gallbladder & biliary system is for the production and storage of bile, which aids in digestion of fat. ***Biliary system*** - consists of bile that is composed of mostly water (82%) and bile acids (12%). The remaining constituents are: cholesterol, bilirubin (bile pigment), proteins, electrolytes, and mucus. Produced in the liver, stored in the gallbladder, and carried to the gastrointestinal system via the bile ducts. **Bile ducts** – are a highway for bile. The **sphincter of Oddi** – is located in the duodenum. It regulates the passage of bile into the duodenum and at the

same time prevents reflux of gastrointestinal fluids into the biliary system. **Cholecystokinin (CCK) –** a peptide hormone is released by the duodenal mucosa when fat and amino acids are ingested. CCK stimulates the sphincter of Oddi to relax and the gallbladder to contract, and increases hepatic production of bile. The gallbladder serves primarily for storage, however, related blood vessels and lymphatics concentrate stored bile through absorption of water and inorganic salts. The gallbladder is variable in size but averages 8-9cms in length and about 3cms in diameter. It holds approximately 40 ml fluid. The wall thickness should not exceed 3 mm. **Common hepatic duct**– varies from one book to another but the accepted maximum average is an inner diameter of 4 mm. **Cystic duct** – The inner diameter of the cystic duct is approximately 3 mm. **Common bile duct (CBD) –** the accepted maximum diameter of the CBD is also highly variable which has been reported to be about **7 mm** pre-surgically and **10 mm** in a patient following cholecystectomy.

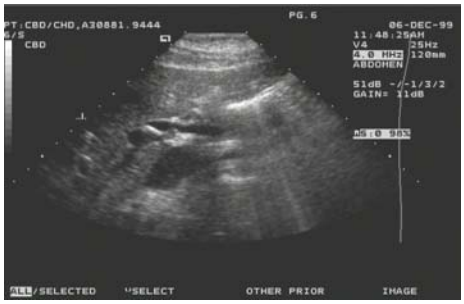
Location – the gallbladder is located in the *gallbladder fossa*, which is the posteroinferior portion of the right lobe of the liver. The gallbladder varies in location due to body habitus but it is generally just inferior to the right portal vein. **Note:** Sometimes the gallbladder is a partially or completely enclosed in liver tissue and this is called an intrahepatic gallbladder. The position of the gallbladder varies with patient position. *Supine*–patient lying in the supine position, the gallbladder is in a normal anatomical location. Patient in the *Left Lateral Oblique or LPO position* – the gallbladder usually shifts medially toward midline. *Biliary ducts* – The right and left hepatic ducts join at the hilum of the liver (also called the porta hepatis) to form the common hepatic duct. The common hepatic duct will eventually form the CBD, entering the duodenum near the head of the pancreas. *CBD (common bile duct)* - is usually located slightly lateral and anterior to the main portal vein. *Mickey Mouse sign* – Locating a cross-section of the portal triad can help identify the CBD in the transverse plane. Mickey's sign is seen in this view, the popular mouse's right ear is the CBD and the left ear is the hepatic artery. *CHD (common hepatic duct)* - is difficult to distinguish from the CBD sonographically unless the cystic duct can be visualized. (Label CD - common duct - when not able to visualize junction).

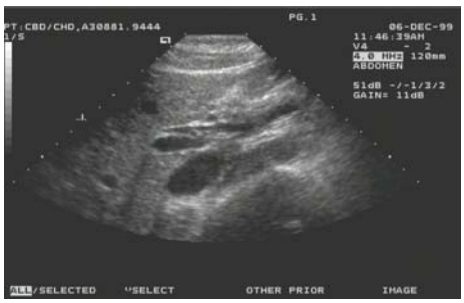


Gallbladder: has a pear shaped appearance and comprised of three sections, the fundus, body, and neck. Gallbladder sections: Fundus – is the rounded portion of the pouch. The fundus is the area where sludge and stones tend to collect. Body – wide middle section between the fundus and neck. Neck – The narrowest portion of the gallbladder. It sometimes contains a small sacculation (out-pouching) called Hartmann's pouch (also called the infundibulum). *Wall layer*s – The gallbladder wall has three layers, the mucosa layer (inner), the fibromuscular (middle), and the outer serous layer. *Rugae* – the inside of the gallbladder contain rugae or tiny folds. These tiny folds aid in

concentrating the bile through absorption of water and secretion of mucus. *Hepatic Ducts* – the intrahepatic ducts run alongside the portal veins and hepatic arteries in portal triads, surrounded by connective tissue and radiate through the lobes and segments of the liver. The intrahepatic ducts, as mentioned earlier, make up the right and left hepatic ducts that form the common hepatic duct at the porta hepatis. Cystic Duct – the lumen of the cystic duct contain a series of mucosal folds called ***valves of Heister*** which prevent the cystic duct from over distending and collapsing during gallbladder contraction and expansion. CBD – joins with the pancreatic duct and connects to the duodenal wall via the ampulla of Vater that contains the sphincter of Oddi.

Sonographic Appearance: Most of the biliary system can be visualized with ultrasound, which explains why ultrasound is the new gold standard for diagnosing gallbladder disease and biliary obstruction. Gallbladder sonographically displays an anechoic appearance with smooth echodense walls. The walls tend to be thicker when the gallbladder is contracted. There should be acoustic enhancement seen posterior to gallbladder free from shadows. **Sonographic location**: Start by scanning in the longitudinal plane and locate the upper border of the right kidney. Proceed to scan medially until the gallbladder is located. *Longitudinal* – A longitudinal view of the gallbladder is usually found in the oblique axis. *Transverse* – A transverse view is obtained by turning the transducer 90° counterclockwise from the longitudinal view.





Sonographic evaluation: The gallbladder should be free of internal echoes and posterior shadowing. The gallbladder should be fully examined by completely sectoring through the organ in the longitudinal and transverse planes. Ductal system should be examined by locating the common duct. The CHD/Cystic duct junction is not usually visualized. We measure the area directly above the cross section of the Hepatic artery and label it CD, for standardization. CBD – is located by following the right portal vein to the main portal vein in its long axis and turning the transducer 90° to view a cross section of the portal triad. Normal variants of the gallbladder (GB): hypoplasia (underdevelopment), agenesis (absent), and duplicated. Common variations: ***Phrygian cap***– is the most common variation where the GB is folded onto itself and looks like a phrygian cap. Bilobed (hourglass), septated, and or folded into several shapes. **Note:** a gallbladder folded on top of itself is commonly mistaken for a septated gallbladder during ultrasound exams.

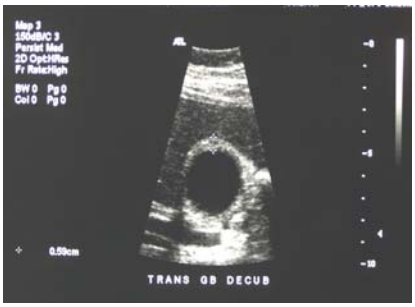
Sonographic Applications: Indications – examinations of the GB and biliary system are indicated but not limited to the following: assessing GB and or adjacent liver masses

determining the presence of gallstones (cholelithiasis) determining the presence of stones in the ductal system (choledocholithiasis) ruling out masses post surgical follow-up (i.e., cholecystectomy).

Clinical symptoms of gallbladder disease:

The most classic symptom of gallbladder disease is right upper quadrant pain, which usually occurs during ingestion of greasy foods. Nausea and vomiting sometimes occur and may indicate the presence of a stone in the common bile duct. A gallbladder attack may cause pain in the right shoulder. Inflammation of the gallbladder is usually the cause of the referred pain to the right shoulder.

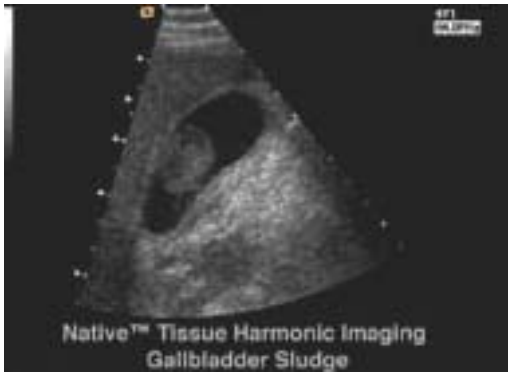
Pathology of the gallbladder:



Cholecystitis: Defined as inflammation of the gallbladder. It is usually chronic illness punctuated by intermittent acute episodes, which occur when the cystic duct is obstructed by a calculus, resulting in inflammation of the gallbladder wall. **Sonographic findings:** suggestive of acute cholecystitis include gallstones, sludge, gallbladder distension, thickened gallbladder wall, pericholecystic fluid, intraluminal membranes, and a positive "Murphy's Sign". Gallstones are almost always associated with cholecystitis, although rare cases of acalculus cholecystitis are believed to occur. Many physicians regard a positive sonographic Murphy's sign and the presence of gallstones as grounds for surgery in the symptomatic patient (77% - 92% predictability). Sonographic Murphy's sign can be described as a patient flinching (as if they were stuck with a needle) when the transducer is pressed on the area of their gallbladder (predictive value of 77% to 92%).

Porcelain Gallbladder: (calcified gallbladder) - an uncommon manifestation of chronic cholecystitis results from chronic inflammation of the gallbladder.

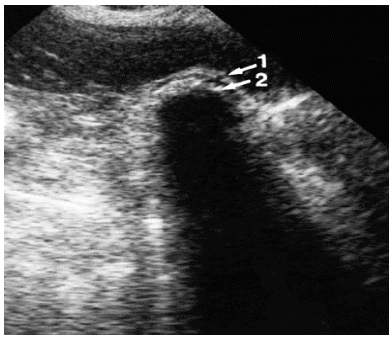
Sludge: is thick low-level internal echoes that may be attributed to thick or inspissated bile. It is often seen in patients with prolonged fasting, extra hepatic bile duct obstruction, various intrinsic disorders of the gallbladder, and sickle cell disease. It is gravity dependent. With alterations in patient position, the sonographer should be able to distinguish sludge from occasional artificial echoes (usually noise and reverberation) found in the gallbladder.



Aggregated sludge may appear as a mobile, non-shadowing echogenic mass (sludgeball). *Tumefactive* sludge may appear as a polypoid mass in the dependent portion of the gallbladder. **Note:** A follow-up scan in a few days or weeks can differentiate aggregate and tumefactive sludge from stone or neoplasm if it (the sludge) disappears.

Wall thickness: Normal gallbladder wall thickness is 1 to 3 mm. Measurements are most accurate when the anterior wall of the gallbladder is scanned in the long-axis view with the sound beam perpendicular to the wall of the gallbladder. *Diffuse* gallbladder wall thickening is a nonspecific finding caused by numerous disorders including cholecystitis, hepatitis, cirrhosis, AIDS, pancreatitis, and renal disease. Occasionally a symmetrically thickened wall is seen in normal patients (usually after a meal). It seems to be related to the degree of contraction of a normal gallbladder. If the thickened wall is localized and irregular, one should consider cholecystitis, adenomyomatosis, or carcinoma of the gallbladder.

Gallstones (Cholelithiasis): the presence of stones within the gallbladder. Specific risk factors include age, obesity, rapid weight reduction, ileal disease or resection, hyperalimentation, elevated triglycerides, or ethnic origin. Stones cast a "clean" posterior acoustic shadow (it has a sharp border and there are no echoes or reverberations within the shadow), as opposed to "dirty" shadowing from bowel gas that has indistinct borders and contains echoes and reverberations. The stones should freely move with changes in patient position. **Note:** Some studies indicate that stones less than 3 mm may not always cast an acoustic shadow. The sonographer must scan the patient in the following positions to evaluate the motility of the stones: supine, left lateral decubitus or upright. After a fatty meal the gallbladder contracts to release bile: if stones block the outflow tract, pain results. Stones are believed to be composed of cholesterol, pigment (calcium bilirubinate), or calcium carbonate. Ninety percent have mixed composition. **Note:** The tiny stones are the most dangerous, since they can enter the bile ducts and obstruct the outflow of bile.

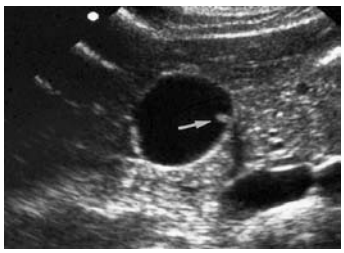


Wall Echo Shadow (WES): When the gallbladder is completely filled with stones, a hyperechoic structure with distal acoustic shadowing is seen within the gallbladder fossa, and a fluid-filled gallbladder cannot be identified. Consists of two parallel arcuate hyperechoic lines separated by a thin hypoechoic space and distal acoustic shadowing,. The proximal hyperechoic arc represents the wall of the gallbladder, the distal hyperechoic arc represents the reflections from gallstones, and the hypoechoic space in between represents either a small sliver of bile between the wall of the gallbladder and the gallstones, or a hypoechoic portion of the wall of the gallbladder.

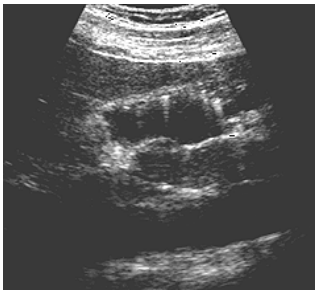
Floating gallstones: Some stones are seen to float when contrast material from an oral cholecystogram is present. This manifestation takes place because the contrast material has a higher specific gravity than that of normal bile. Gallstones seek a level where their specific gravity equals that of the mixture of bile and contrast material. *Fissured stones* will float even in the absence of contrast due to the presence of gas contained within the fissures.

Choledocholithiasis: is defined as a stone located within the common bile duct.
Note: Stones tend to impact the ampulla of Vater and may project into the duodenum.
Jaundice – it is characterized by the presence of bile in the tissues with resulting yellow-green color of the skin. Stones or disease that obstructs the bile ducts producing pressure on the liver and forcing bile into the blood may cause it.

Neoplasms of the gallbladder: Benign – True benign tumors of the gallbladder are very rare.

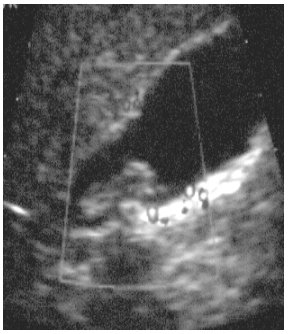


Adenomas: adenomatous polyps appear as solitary echogenic, non-mobile, non-shadowing structures protruding from the inner wall of the gallbladder. They are uncommon and difficult to distinguish from cholesterol polyps. Malignancy should be considered when the polyp exceeds 1 cm in diameter.



Adenomyomatosis: Characterized by epithelial proliferation, muscular hypertrophy, and mucosal diverticula and described as *diffuse, segmental, or focal. Diffuse* – Involves entire gallbladder. *Segmental* – Segmental thickening usually of the mid gallbladder wall (hourglass-shaped gallbladder). *Localized* - Most commonly confined to the fundus causing focal thickening (may appear as a solid mass mimicking a carcinoma).

Cholesterol polyp: (Pseudotumors of the gallbladder) - it is the most common pseudotumor of the gallbladder. Ultrasound findings: they appear as small elevations in the gallbladder lumen and are difficult to distinguish from adenomatous polyps. These elevations maintain their initial location during positional changes, and there is no acoustic shadowing.



Malignant - Primary carcinoma of the gallbladder is very rare. The tumor arises in the body of the gallbladder or, rarely, in the cystic duct. The tumor infiltrates the gallbladder locally or diffusely and causes thickening and rigidity of the wall. Most malignant gallbladder tumors are adenocarcinoma. They are associated with gallstones and/or porcelain (calcified) gallbladders. **Clinical symptoms:** Clinical features are often non-specific and may include RUQ pain, anorexia, weight loss, and jaundice. **Sonographic findings:** The most frequent sonographic sign is a large, irregular, fungating mass that contains low-intensity echoes with the gallbladder. **Note:** This mass may completely fill the gallbladder, obscuring the walls. It may appear as an intraluminal polypoid mass larger than 2 cm. The gallbladder wall is markedly abnormal and thickened. The adjacent liver tissue in the hilar area is often heterogeneous because of direct tumor spread. There may also be dilated biliary ducts within the liver parenchyma, causing the "shotgun" sign (a "double barrel" of portal veins and dilated ducts).

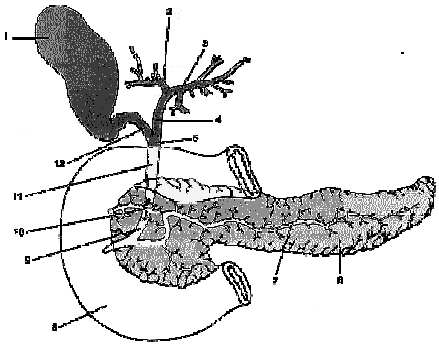
Pathology of the bile ducts:

Carcinoma of the Bile Ducts: The sonographic appearance of tumors in the bile ducts (cholangiocarcinomas) has the same sonographic appearance as primary tumors of the pancreas or liver (depending upon the location of the mass).

Note: Due to their similar appearance, differentiating between bile duct tumors and hepatic or pancreatic tumors it is not usually directly diagnosed with ultrasound.

Other Pathology of the Bile Ducts:
Cholangitis: Inflammation of the bile ducts walls and ductal dilation.
Choledochal Cyst: A congenital abnormality that appears as a cystic dilation of any portion of the biliary tree, most commonly the CBD.
Biliary Atresia: Thought to be a congenital absence of a normal opening to the major biliary ducts in infants causing intrahepatic bile duct dilation and persistent jaundice.

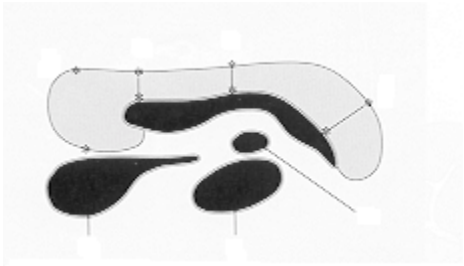
PANCREAS:



Physiology: The pancreas has two major functions, a digestive (exocrine) function and a hormonal endocrine function. ***Exocrine:*** The gland is mostly exocrine...only two percent of the gland's weight is endocrine tissue. *Acini cells:* They carry out the exocrine function of the pancreas; they can produce up to two liters of pancreatic juice per day. They resemble grape clusters with small areas of endocrine tissue interspersed between. *Pancreatic juice* is composed of *pancreatic enzymes* that help digest fats, proteins, carbohydrates, and nucleic acids. *Pancreatic enzymes* are composed of amylase (digests carbohydrates), lipase, (digests fat), trypsin, chymotrypsin, carboxypepidase, (digest proteins), nucleases, (digests nucleic acids), and the largest component sodium bicarbonate (neutralizes hydrochloric acid produced in the stomach). **Note:** the cells lining the pancreatic duct produce Sodium bicarbonate. Hormone physiology–starts when chyme (partially digested food) is detected in the duodenum, which stimulates the secretion of hormones, which stimulate the secretion of pancreatic juice. The hormones produced by the body are: *Cholecystokinin, gastrin, and acetylcholine* (all three stimulate the acini cells to produce digestive enzymes). *Secretin (*stimulates the production of sodium bicarbonate). *Pancreatic duct:* All exocrine juice is carried to the duodenum via the pancreatic duct which connects to the common bile duct. **Note:** The pancreatic duct is also called the *duct of Wirsung.*
Endocrine broken up by cells that produce each following functions:

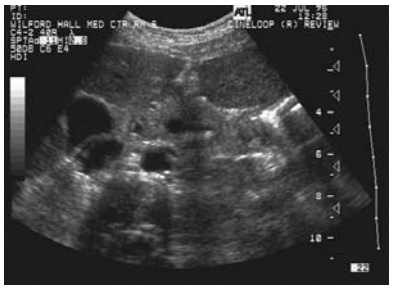
- *Alpha cells* – comprise 15 to 20 percent of the endocrine tissue and produce glucagon, which is a substance that causes the liver to convert glycogen to glucose – increases blood sugar levels.
- *Beta Cells* – comprise 60 to 70 percent of the endocrine tissue and produce insulin, which causes the liver to change glucose into glycogen - reduces blood sugar levels.

- *Delta cells* – a very small percentage of endocrine tissue, which produces somatostatin, a hormone that inhibits the production of insulin and glucagon. The l*ength* varies between 12 and 18 cm, 2.5 cm thick, 3 to 5 cm wide and weighs between 60 and 80g.



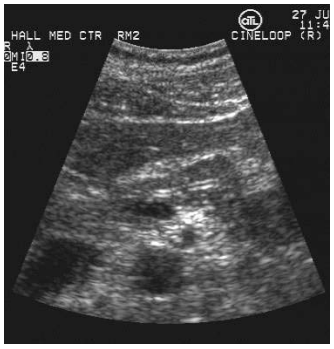
The *AP measurement* is taken at the head primarily but sometimes the neck, body, and the tail maybe measured. *Head*– **3 cm,** *Neck*– **1 cm,** *Body*– **2.2 cm,** *Tail*– **2.8 cm**

Location: Pancreas is located in the epigastrium and left hypochondrium. It lies horizontally across the aorta in an upside down "U" shape that looks like the ends have been pulled apart. It is mostly retroperitoneal, however, part of the head is peritoneal. Structures adjacent to the pancreas: *Anterior to pancreas* – stomach and transverse colon. *Posterior to pancreas* – IVC, SMA, Aorta, and diaphragm. Pancreatic sectional locations: *Head* is cradled in the c-loop of the duodenum and is anterior to the IVC. *Neck* is anterior to the superior mesenteric vein and portal/splenic confluence. *Body* is anterior to the SMA. The splenic vein lies just posterior to the body and tail closely following the shape of the gland. *Tail* can be seen near the hilum of the spleen.



Pancreas – consists of four parts: head, neck, body, and tail. The head has two vessels that can be seen in this segment: the common bile duct in the posterior portion and the gastroduodenal artery in the anterior portion. *Uncinate process* is a posteromedial projection of pancreatic tissue, which extends from the head. The *Neck* is located between the pancreatic head and body. The *Body* is the portion that follows the splenic vein and is located between the neck and the pancreatic tail. The *Tail* extends laterally from the body and continues towards the spleen. Pancreatic blood supply comes from the pancreaticoduodenal arteries, the pancreatic arcades, and branches of the splenic artery. Pancreaticoduodenal arteries arise from the gastroduodenal artery, which feed the head of the pancreas. P*ancreatic arcades* are made by segments of the hepatic, splenic, and superior mesenteric arteries, which feed the pancreatic head. Splenic artery supplies the body and tail. It has many individually named segments, which are not important to the sonographer.

Sonographic Appearance: The pancreatic echogenicity varies but usually demonstrates a slightly more echodense appearance than the typical liver, although the texture isn't as homogeneous.

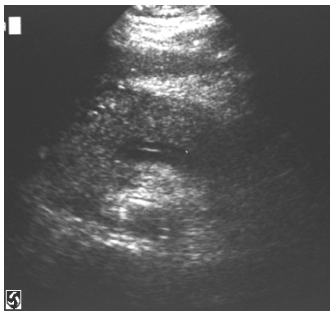


Sonographic evaluation: The borders of the pancreas are usually well defined with a smooth curvilinear contour with no enlargement compared to the other pancreatic segments. **Note:** Masses in the pancreas will be readily apparent. *Pancreatic duct* is seen as two short, highly reflective lines spaced **2 mm** apart within the body of the pancreas. *Stomach* is seen lying anterior to the pancreas and quite often obscures the visibility of the pancreas. *Imaging pitfalls* – A common pitfall is suspecting pathology when the questionable area is only the overlying stomach and duodenum.

Scanning planes: ***Transverse*** – a long axis of the pancreas is seen, surrounded by epigastric vessels. Head – demonstrates two vessels, the common bile duct (posterior) and the gastroduodenal artery (anterior). Neck, body & tail are seen anterior to the portal confluence, the SMA, and eventually the body and tail course along the splenic vein. ***Longitudinal*** – sagittal views of the pancreas show the pancreas in transverse segments.

Sonographic Applications: Examinations of the pancreas are indicated but not limited to the following: identification of pancreatic masses, diagnose and follow-up of acute and chronic pancreatitis, diagnose and follow-up of pancreatic pseudocysts.

Laboratory tests: **Amylase** - In acute pancreatitis the digestive enzymes of the pancreas escape into surrounding tissue, producing necrosis with severe pain and inflammation. A serum amylase level of twice normal usually indicates acute pancreatitis. In chronic pancreatitis, the serum level amylase is not elevated. Other conditions that may cause an increase in amylase are mumps, ischemic bowel disease, and pelvic inflammatory disease. **Lipase** - It is a test performed to assess damage to the pancreas. The lipase level rises in acute pancreatitis and in carcinoma of the pancreas. **Glucose** - The glucose tolerance test is performed to discover whether there is a disorder of the glucose metabolism. An increased blood glucose level is found in severe diabetes, chronic liver disease, and over activity of several endocrine glands.



Pancreatitis - is defined as an inflammation of the pancreas.
Acute pancreatitis: It is defined as the sudden onset of pancreatitis with biliary tract disease as the most common cause. **Note:** Alcohol abuse is the second most common cause of pancreatitis. When damage to the acinar tissue and duct system occurs, this results in leakage of pancreatic juice into the middle of the gland or into the peripancreatic tissues, or both. If the acini or duct disrupts, the secretions migrate to the surface of the gland and sometimes will form pseudocysts or spill into the lesser sac of the peritoneum. **Clinical signs:** Moderate-to-severe tenderness in the epigastrium radiating to the back. Fever is present, along with leukocytosis. The patient may be at risk for abscess and hemorrhage secondary to pancreatitis. **Other complications:** Patients with acute pancreatitis may go on to develop other complications such as: pseudocyst formation (10-20%), phlegmon (18%), abscess (1-9%), hemorrhage (5%), or duodenal obstruction. **Ultrasound findings:** Early stages of acute pancreatitis may not show swelling. When swelling does occur, the gland is hypoechoic to anechoic and is less echogenic than the liver. The borders may be somewhat indistinct but smooth. Longitudinal scans may demonstrate anterior compression of the IVC, which is caused by the swollen head of the pancreas. The pancreatic duct may be obstructed in acute pancreatitis as a result of inflammation, spasm, edema, swelling of the papilla, or pseudocyst formation. Associated findings also include dilation of pancreatic duct beyond 2 to 2.5 mm.

Hemorrhagic pancreatitis: Defined - It is a rapid progression of acute pancreatitis. It is usually caused by a sudden escape of pancreatic enzymes into the glandular parenchyma of the pancreas. These enzymes cause a breakdown of the glandular tissue that leads to rupture of the pancreatic vessels and hemorrhage. Nearly half of the patients have sudden necrotizing destruction of the pancreas after an alcoholic binge or an excessively large meal. **Clinical signs:** Severe pain radiating to the back, with subsequent shock and ileus. Lab values may show a decreased hematocrit and serum calcium level. Patients may be hypotensive despite volume replacement with metabolic acidosis and adult respiratory distress syndrome. **Ultrasound findings:** Depends on the age of the hemorrhage. A well-defined homogeneous mass in the area of the pancreas may be seen with areas of fresh necrosis. Further necrosis of the blood vessels results in development of hemorrhagic areas referred to as Grey Turner's sign (discoloration of the flanks). At one week, the mass may appear cystic with solid elements or septations. **Note:** After several weeks the hemorrhage may appear cystic. **Acute pancreatitis in children** - It is more easily seen because there is less body fat to interfere with visualization. In acute pancreatitis, the gland is increased in size with a hypoechoic pattern and an indistinct outline. Acute pancreatitis may result from trauma, drugs, infection, hereditary pancreatitis, or congenital anomalies. **Complication of pancreatitis (Abscess)** - The

condition is related to the degree of tissue necrosis. The majority of patients develop an abscess secondary to pancreatitis, which develops from postoperative procedures. A very high mortality rate is associated with this condition. An abscess in the pancreas may arise from a neighboring infection and spread to other areas as well. **Clinical signs:** Persistent fever and leukocytosis. The patient may also have chills, hypotension, and a tender abdomen with a growing mass. It may also develop 7 to 14 days after the onset of symptoms of acute necrotizing pancreatitis. **Ultrasound findings:** Smooth or irregular thick walls, causing few internal echoes; it may be echofree to echodense. If air bubbles are present, an echogenic region with a posterior shadow is imaged.

Chronic pancreatitis results from recurrent attacks of acute pancreatitis and causes continuing destruction of the pancreatic parenchyma. It is generally associated with chronic alcoholism or biliary disease. **Clinical signs:** Epigastric pain progressing with the disease, gastrointestinal problems, and jaundice secondary to common duct obstruction if left untreated. **Ultrasound findings:** It may appear as a diffuse or localized involvement of the gland. Echogenicity of the pancreas is increased beyond normal because of fibrosis and calcification. The borders are irregular. The duct may be dilated secondary to stricture or as the result of an extrinsic stone moving from the smaller pancreatic duct into a major duct. There are calcifications of the gland in 20% to 40% of patients. The pancreatic duct may dilate and contain calculi. **Note:** With ductal lithiasis, shadowing may be present.

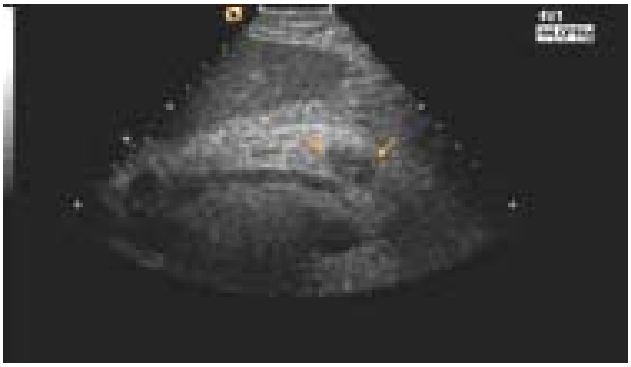
Pancreatic cysts (2 Types)

1) **True cysts** – may be congenital or acquired, they have the same sonographic appearance as any simple cyst in the abdomen.
2) **Pseudocysts** - they result from trauma to the gland or acute or chronic pancreatitis. **Note:** They are always acquired. 10% to 20% of patients with acute pancreatitis develop a pseudocyst. It is defined as a collection of fluid (pancreatic enzymes) that arises from the loculation of inflammatory processes, necrosis, or hemorrhage. **Locations of a pseudocyst:** the most common location is the lesser sac, anterior to the pancreas, and posterior to the stomach. **Clinical symptoms:** the patient is usually asymptomatic until it becomes large enough to cause pressure on surrounding organs. **Sonographic findings:** They appear as well-defined masses with, essentially, sonolucent echofree centers. Because of debris, scattered echoes may be seen at the bottom of the cysts. Increased through transmission is also present. The borders are very echogenic, and the cyst wall usually is thicker than other simple cysts. Atypical pseudocysts may have septations, excessive internal echoes, and lack posterior enhancement.

Pancreatic tumors

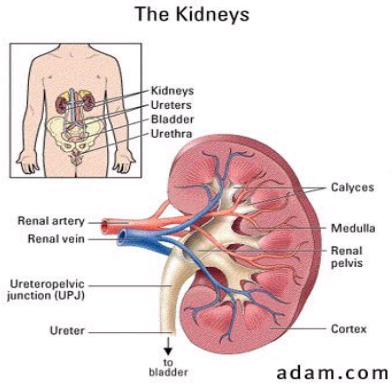
Macrocystic Adenoma: It is a rare benign disease found more often in females. Tiny cysts are found primarily in the body and tail (60%). **Ultrasound findings** – These cystic neoplasms look similar to pseudocysts and may have the following ultrasound patterns: Well-circumscribed multilocular or septated cystic masses or complex predominately cystic mass with internal homogeneous echoes. Complex predominately cystic mass with irregular internal vegetations (papillary excrescences of solid tissue) protruding into the

lumen and showing no movement. Completely echogenic masses with nonhomogeneous pattern (microcystic adenoma). The cysts themselves are too small to be resolved.



Adenocarcinoma - it is the most common primary neoplasm of the pancreas. This fatal tumor involves the exocrine portion of the gland and accounts for 95% of all malignant pancreatic tumors. It usually occurs in 60 to 80-year-old males and occurs less often in females. The most frequent sites of occurrence are in the head of the gland (70%), with 20% to 30% in the body, and 5% to 10% in the tail. The tumors in the head present early, causing obstruction of the common bile duct and hydrops of the pancreas. **Clinical signs:** Symptoms usually occur late. The time from symptoms to diagnosis is 4 months: the time to death from initial symptoms is 8 months to 1.6 years. The most common symptom is pain radiating to the back or a dull, steady, aching mid-epigastric pain. Other clinical symptoms – weight loss, painless jaundice, nausea, vomiting, fever, leukocytosis, and changes in stools. The presence of a dilated gallbladder and a palpable mass is strongly suggestive of carcinoma. **Ultrasound findings:** A loss of normal pancreatic parenchymal pattern. The lesions represent localized change in echodensity of the pancreas. The echo pattern is hypoechoic or less than the pancreas or the liver. There may be secondary enlargement of the common duct resulting from edema or tumor invasion of the pancreatic head. Also, there may be a "double duct" sign, which refers to simultaneous dilation of the pancreatic and biliary ducts. When tumor involves the head of the pancreas most patients present with obstructive jaundice and anterior wall compression of the IVC. The sonographer should look for paraortic nodes and metastatic spread into the liver.

URINARY SYSTEM:



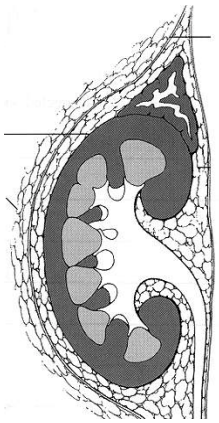
Prenatal development – has three stages, pronephros, mesonephros, metanephros, pronephros, and mesonephros appear in the fourth to fifth week of gestation and is precursors to metanephros. *Mesonephric ducts* (Wolfian) drain the embryonic kidneys. *Paramesonephric ducts* (Mullerian) which are located alongside the Wolfian ducts are the sites where the reproductive organs develop. *Metanephros (*the permanent kidney) appears toward the end of the fifth week of gestation. The kidneys originate in the pelvic cavity and as the embryo grows, the kidneys move up into the abdomen.

Physiology – The kidney has two major functions, urine production through filtration and homeostasis (maintenance of normal body physiology). *Urine production* – The kidneys filter approximately 1200 ml per minute and produce on average 1500 ml of urine per day. Excreted urine is 95 % water and 5 % nitrogenous wastes and inorganic salts. Nitrogenous wastes are byproducts of metabolism. *Nephron* is the functional unit of the kidney and is located primarily in the cortex. All filtration is performed within the nephron. It performs two functions: filters blood, produces urine. *Nephron physiology*– The nephron consists of two main structures, a renal corpuscle and a renal tubule. *Renal corpuscle* – Blood is filtered in the renal corpuscle. *Renal tubule* – The filtered fluid passes through the renal tubule. As the filtrate moves through the tubule, substances needed by the body are returned to the blood. Waste products, excess water, and other substances not needed by the body pass into collecting ducts as urine. Nephron Blood-flow – Blood reaches the nephron in the following manner: Blood enters the kidney through the *renal artery.* The renal artery forms *interlobar arteries*, which travel in-between the renal pyramids. The interlobar arteries branch into the *arcuate arteries*, located at the base of the renal pyramids. From the arcuate arteries, the *interlobular arteries* travel into the *renal cortex.* The *interlobular arteries* then branch into the *afferent arterioles*, which carry blood into the *glomerulus* of the nephron. *Homeostasis*– is controlled by the kidney's ability to regulate blood volume. There are four biochemical responses. *Antidiuretic hormone (ADH)* – a product released from the posterior pituitary gland when low blood volume is detected which causes the kidneys to retain water. *Aldosterone* – is produced by the *adrenal cortex* when low blood volume is detected. Aldosterone causes the kidneys to reabsorb s*alt & water* which increases blood volume. Renin is released due to low blood volume and is *released by* the granular cells in the afferent arteriole. It acts as is an angiotensinogen in the blood, which increases systematic pressure in the body. *Erythropoietin* – is released by the kidneys in response to a decrease in oxygen (e.g., due to hemorrhage). Erythropoietin acts on bone marrow, causing mature red blood cells to be released in the bloodstream and new cells to be produced.

Lab tests: are performed to check renal function. *Blood urea, nitrogen (BUN), and Creatinine (Cr)* are functional tests that measure the kidneys ability to get rid of nitrogenous wastes. Normal values for BUN and Cr are BUN 26 mg per dl and Cr 1.1 mg per dl. *Specific gravity* assesses the kidneys ability to concentrate urine. It is the measure of how much material is dissolved in the urine. The higher the dissolved content in the urine, the higher the specific gravity. The normal lab range is 1.025 to 1.101.

Size: *Adult kidney* measures between **9 and 12 cm** in length**, 2.5 cm to 4 cm** thick, and **4 to 6 cm** in diameter. *Pediatric kidney* is proportionally larger than the adult and may extend inferiorly to the iliac crest. *Ureters* range from **25 to 30 cm** in length. The diameter ranges between **4 and 7 mm**. *Bladder* – size depends on the quantity of contained urine. The bladder wall normally measures between 3 **and 6 mm** depending on the degree of bladder distention. Urethra Male– 20 cm Female– 3.5 cm.

Location: The kidneys are bean-shaped, retroperitoneal organs that lie on each side of the spine between the twelfth thoracic and fourth lumbar vertebrae. Renal characteristics - the kidneys have a convex lateral border and a concave medial border. *Right & left renal differences* – the liver displaces the right kidney inferiorly hence it is lower than the left kidney and also has a shorter ureter. **Anterior renal borders:** *Right renal* – Anterior to the right kidney is the right adrenal gland, the right lobe of the liver, the second part of the duodenum, the hepatic flexure, the jejunum and the ileum of the small bowel. *Left renal*– Anterior to the left kidney are the left adrenal gland, pancreatic tail, the spleen, jejunum, stomach, and the splenic flexure. **Posterior renal borders:** Posterior to both kidneys is the diaphragm, psoas muscles, the transversus muscle, and the quadratus lumborum muscle. *Ureters* are tubular retroperitoneal structures that start at the renal hilum and course inferiorly toward the posterior segment of the urinary bladder bilaterally. *Bladder* is retroperitoneal organ that is located in the pelvis, posterior to the symphysis pubis. *Male bladder* is anterior to the seminal vesicles and the rectum, and superior to the prostate gland. *Female bladder* is anterior to the vagina, posterior cul-de-sac, and the rectum. *Urethra* – exits the neck of the bladder inferiorly. *Adrenal glands* are located at the medial and superior borders anterior to both kidneys.



Gross Anatomy: *Kidney's* Protective *coverings* – The kidney contains several protective coverings that cushion and protect the organ. *First layer "true capsule"*– is a tough fibrous capsule. *Second layer* – is a perirenal fat layer that surrounds the kidney; it is continuous with the renal sinus. *Third layer* – is the renal fascia or Gerota's fascia. Surrounds the kidney and perirenal fat. Anchors the kidney and limits any infection arising from them. *Fourth layer* – is another fat layer called, pararenal fat. **Note:** The para and peri renal fat layers accommodate kidney movement during respiration. *Renal parenchyma* consists of two areas, cortex and medulla. *Cortex* is the outer portion of the parenchyma which contains the renal corpuscle and part of the renal tubule of the

nephron. *Medulla* is the inner portion of the parenchyma, which contains most of the renal tubule. *Pyramids* – the medulla consists 8 to 18 medullary pyramids that are triangular structures with a narrow tip, called the apex, and a broad base. The pyramids deliver urine to the minor calyces. *Columns of Bertin* are bands of cortical tissue which separate the renal pyramids. *Renal sinus* is the central portion of the kidney. It contains the minor & major calyces, the renal pelvis, renal artery & vein, fat, nerves, and lymphatics. *Minor calyces* – The minor calyces feed the major calyces. *Major calyces* – There are usually two or three major calyces, which convey urine to the expanded upper end of the ureter, the *renal pelvis*.

Adrenal glands: are seldom seen with ultrasound so it will only be briefly discussed. Size: 2 inches (5cm) in length, 1.1 inches (2.8cm) in diameter, and .4 inches (1cm) in depth. The glands are enclosed with the kidneys by Gerota's fascia and surrounded by fat. Each gland consists of two layers 1) *Cortex*– secretes steroid hormones, which regulate metabolic functions within the body. 2) *Medulla*– secretes the hormones responsible for the "fight or flight" response (epinephrine and norepinephrine).

Ureters: consists of three layers of tissue 1) *Inner layer*– mucosal layer 2) *Middle layer*– muscular layer 3) *Outer layer*– fibrous layer. The ureters carry urine from the kidneys to the bladder, which insert at the trigone.

Bladder: the bladder consists of four layers: inner mucosa, submucosa layer, the muscularis and the outer serosa. *Inferior portion* – is composed of a posterior base (trigone area) and the neck, which communicates with the urethra.

Urethra: consists of a membranous hollow canal that conveys urine from the bladder to the outside. *Male urethra* is 20 cm in length and is comprised of three sections. *Prostatic urethra* is the proximal section. It receives secretions from the prostate gland. *Membranous urethra* is the middle part that which pierces the urogenital diaphragm. *Penile urethra* is the longest segment and extends the entire length of the penis. *Female urethra* is 3.5 cm in length and is comprised of only one segment.

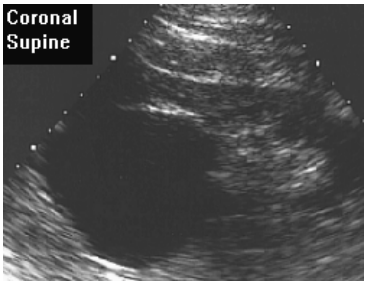
Normal Urinary Variants: *Dromedary hump* is a localized bulge on the lateral border of the kidney. It has the same sonographic appearance as renal tissue. *Hypertrophied column of Bertin* occurs in varying degrees of size and may indent the renal sinus. It has the same sonographic appearance as a normal renal cortex. *Double collecting system* occurs when the renal sinus is divided. Each sinus has a renal pelvis. A bifid ureter may also be present. *Horseshoe kidney* occurs when the kidneys are connected, usually at the lower poles. *Renal ectopia* occurs when one or both kidneys are outside the normal renal fossa.

Sonographic Appearance: Longitudinal – The adult kidney appears as a smooth, contoured elliptical structure. *Transverse* – The kidney appears rounded and broken medially by the hilum. The renal vein and artery can be seen entering the hilar region. *Tissue specific appearance* – the description begins with the outer edge and ends with the center of the kidney. *True capsule* – appears echogenic and surrounds the cortex.

Parenchymal cortex – appears as mid-gray or medium to low level homogeneous echoes that are less than or equal to the normal liver or spleen. *Medullary Pyramids* appear as triangular, round, or blunted hypoechoic areas when compared to the more urine-filled anechoic areas. Arcuate vessels appear as echogenic dots that may be seen at the corticomedullary junction. Sinus appears as the echogenic center of the kidney. The sinus is echogenic due to surrounding fat. The renal pelvis is not usually seen if collapsed, otherwise it appears anechoic. **Ureters/Urethra** – not usually visualized unless dilated or obstructed. **Urinary bladder**: Transverse – The bladder appears somewhat squared laterally by the psoas muscles. Longitudinal - The posterior surface may by indented by an anteverted uterus or enlarged prostate. The bladder should have a symmetrical, hypoechoic appearance.

Sonographic Applications: examinations of the kidneys are indicated, but not limited to the following: detection and composition of renal masses and cysts, urinary system obstruction, renal abscess, urinary bladder masses, renal transplantation, doppler evaluation for renal artery stenosis, ultrasound guided needle biopsies and aspirations.

URINARY SYSTEM PATHOLOGY:

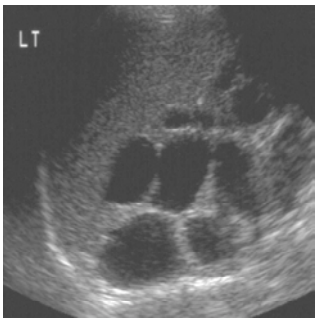


Renal cystic disease: Simple renal cysts are common, occurring in half of the adults over 50 years of age. They may be located anywhere in the kidney. Although most lie within the cortex (cortical), they may also be peripheral, extending from the surface of the kidney (exophitic), or lie centrally, originating in the columns of Bertin. They are often multiple, but are not clinically significant unless they distort the adjacent calyces or produce hydronephrosis or pain. **Sonographic appearance:** They should have all the characteristics of a simple cyst. Well-defined mass-lesion, smooth walls, circular anechoic mass, through transmission. **Size:** Usually 4 cm or less, but can occasionally reach a considerable size of more than 10 cm.

Parapelvic cyst: Defined as a simple cyst, histologically different then a cortical cyst, located in the renal hilum but does not communicate with the renal collecting system. **Clinical symptoms** are infrequent; the cyst can cause pain, hypertension, or obstruction. **Sonographic appearance:** Well-defined mass with no internal septations. It may have irregular borders because it may compress the adjacent renal sinus structures.

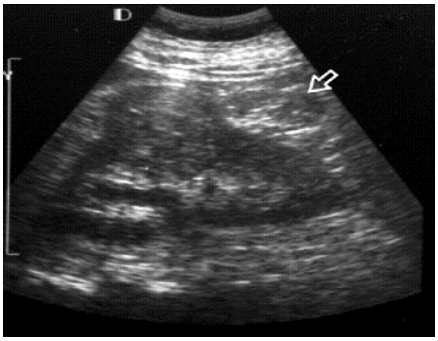
Polycystic renal disease: It may be present in two forms, the *infantile autosomal-recessive form* and the *adult autosomal-dominant form*. Infantile form – The fetus may present with large echogenic kidneys and progress to renal failure and intrauterine demise Adult form - It presents later in life with hypertension and renal failure that is less severe

in onset. The kidneys are enlarged bilaterally with multiple cysts of varying sizes. The cysts may grow large enough to obliterate the renal sinus. The cysts may have spontaneous bleeding, causing flank pain for the patient. Associated abnormalities include Circle of Willis aneurysm (20%), liver cysts (50%), splenic cysts (10%), and pancreatic cysts (10%).



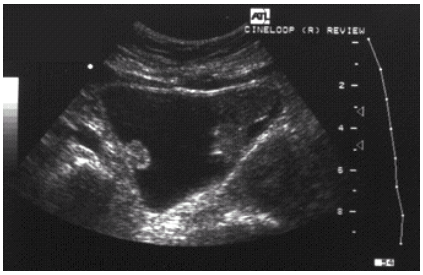
Multicystic dysplastic kidney: It is a nonhereditary renal dysplasia that usually occurs unilaterally. It is caused by obstruction within the first 10 weeks of intrauterine life. **Note:** Bilateral disease is incompatible with life. In neonates and children, the kidneys are enlarged; in adulthood, they may be small and calcified. The typical pattern is multiple cysts of varying size with no normal renal parenchyma. The following other findings may also be present: *Ureteral atresia* - contralateral ureteropelvic obstruction in 30% of patients. *Nonfunctioning kidney* - atretic renal artery is the most common palpable abdominal mass in neonates. **Acquired Renal Cystic Disease (Dialysis Cysts)** Seen bilaterally in patients who have been on long-term dialysis. The cysts vary in size, but are relatively small. May undergo malignant change.

Renal Neoplasm's



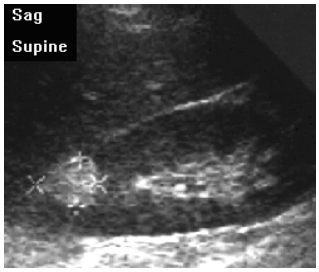
Renal cell carcinoma: It is the most common of all renal tumors, comprising 85% of all kidney tumors. It is twice as common in males than females. The incidence does not peak until age 60 or 70. **Sonographic findings:** It usually presents as a solid parenchymal mass, frequently with areas of hemorrhage or necrosis. It may also appear hypoechoic, or isoechoic. It is not usually echogenic unless calcification is present. **Note:** Any calcified mass within the kidney indicates the possibility of tumor; a sonographer should define the full extent of involvement by scanning the renal veins and IVC. Characteristically the mass is cystic or complex on ultrasound. A hypertrophied Column of Bertin can appear mass-like. It can displace surrounding fat and pyramids, but does not invade them. If there is a doubt, a Nuclear Medicine scan can distinguish

between a Column of Bertin and a renal mass (the Column of Bertin takes up the isotope, whereas the renal tumor gives a "cold" area. Dromedary Humps - Isoechoic protuberances from the renal outline, particularly on the left, may be innocent bulges or splenic (dromedary) humps. With these, also, their shape and position usually are characteristic and calyces extend partly into them, whereas tumors destroy or displace calyces medially.



Transitional cell carcinoma: It is the most common tumor of the renal collecting system. The tumor is often multiple and the incidence is three to four times higher in males than females. **Clinical symptoms:** The patient may present with history of blood in the urine. **Ultrasound findings:** a mass in the renal pelvis which shows low level echoes, widening of the central sinus echoes, and a hypoechoic central area.

Wilm's tumor (nephroblastoma): it is the most common solid renal mass of childhood older then 1 year of age. It is rare in the newborn; incidence peaks in the second year of life. Half of the tumors occur by the child's third birthday. Most tumors occur before age 5. The tumor is associated with Beckwith-Wiedemann syndrome, sporadic aniridia (no color in the eye), omphalocele, and hemihypertrophy (one side of the body larger than the other). **Clinical findings:** Palpable abdominal mass (most common). Other findings include: abdominal pain, anorexia, nausea and vomiting, fever, and gross hematuria. **Ultrasound findings:** The tumor usually appears as a large solitary mass extending from the kidney. The tumor may spread beyond the kidney and invade the venous channel with tumor cells extending into the IVC and eventual metastases into the lungs, local lymph nodes, and liver.

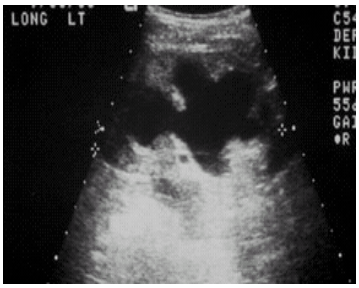


Angiomyolipoma: it is an uncommon benign renal tumor composed mainly of fat cells. It is intermixed with smooth muscle cells and aggregates of thick-walled blood vessels. There may be hemorrhage in the tumor itself or in the subcapsular or perinephric space. **Sonographic findings:** Focal, hyperechoic mass is its typical appearance.

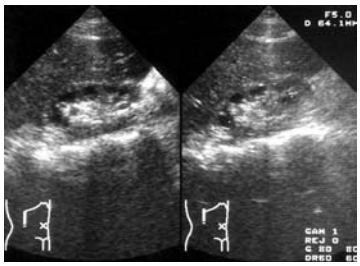
Adenomas: Are common benign renal tumors. Can have calcifications. **Benign verses Malignant -** to separate malignant from benign tumors the sonographer should look for

the following: Vascular flow patterns, Presence of nodes, Metastases surrounding the structure or adjacent to the kidney. **Note:** Ultrasound may distinguish the composition of a tumor, but it cannot indicate the histologic nature of the mass.

Malfunctioning kidney: There are many factors and pathologic processes that affect kidney function, only the most common processes will be discussed.

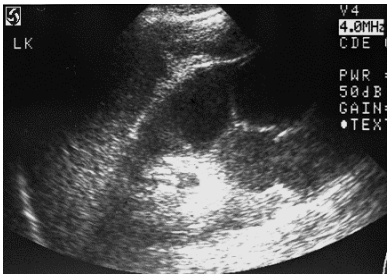


Hydronephrosis: Is defined as the separation of renal sinus echoes by interconnected fluid-filled areas. If hydronephrosis is suspected, the sonographer should evaluate the bladder. **Note:** If the bladder is full, a post void longitudinal scan of both kidneys should be performed to show that the hydronephrosis has resolved or remained the same. There are three grades of hydronephrosis:
Grade I– entails a small separation of the calyceal pattern, also known as splaying.
Grade II– shows the bear-claw effect, with the fluid extending into the major and minor calyceal systems.
Grade III– represents massive dilation of the renal pelvis with a loss of renal parenchyma. **Sonographic evaluation:** Always look for a dilated ureter, enlarged prostate, or a bladder mass, which could be the cause of the hydronephrosis. An ureterocele may also block urine output. This condition occurs when the ureter turns inside out and obstructs the orifice where the ureter inserts into the bladder wall. False positive – Many conditions may mimic hydronephrosis such as: Extrarenal pelvis, parapelvic cysts, reflux, transient diuresis, renal vein or artery abnormalities.

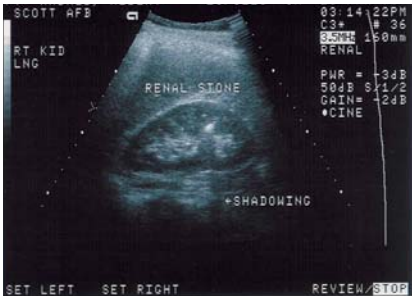


Chronic renal disease: It appears as a diffusely echogenic kidney with loss of normal anatomy.
Type I change = only the cortex is hyperechoic.
Type II change = the cortex and medullary portions of the kidneys become hyperechoic. It is a nonspecific ultrasound finding – chronic renal disease can be caused by multiple etiologies (AIDS can also produce echogenic kidneys). If chronic renal disease is bilateral, small kidneys are identified. **Note:** This may result from hypertension, chronic inflammation, or chronic ischemia. If both kidneys are less than 6 cm in length, they are

classified as “end-stage”, indicating that, whatever the cause, insufficient cortical tissue remains for adequate function.



Pyonephrosis - This condition occurs when pus is found within the obstructed renal system. It is often associated with severe urosepsis and represents a true urologic emergency that requires urgent percutaneous drainage. It usually occurs secondary to long-standing ureteral obstruction from calculus disease, stricture, or a congenital anomaly. **Ultrasound findings** – include the presence of low-level echoes with a fluid debris level. **Note:** The sonographer should be aware that an anechoic dilated collecting system could occur.



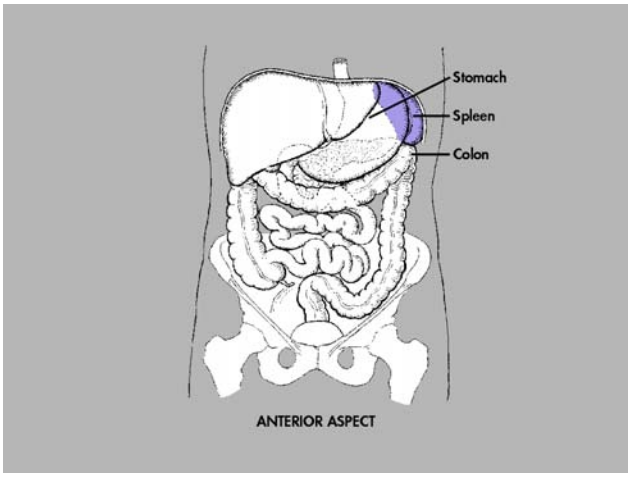
Nephrocalcinosis (kidney stones) - This disease process shows very echogenic pyramids with or without associated shadowing. Renal stones are very echogenic with posterior shadowing. **Clinical symptoms** – The patient may present with fever, this may indicate infection with hydronephrosis. **Ultrasound technique** – When searching for renal stones, one should scan along the lines of the renal fat; usually stones are very small and may not shadow.

Renal vein thrombosis - ultrasound findings include the following: Direct visualization of thrombi in the renal vein and inferior vena cava. Demonstrated renal vein dilation proximal to the point of occlusion. The echodensity of the kidney may be altered with areas of increased and decreased echodensity from hemorrhage and edema. *Increased renal size* - doppler shows decreased or no venous flow with arterial flow demonstrating a narrow systolic peak and sharp reversal of diastolic flow. **Clinical signs:** are pain, nephromegaly, hematuria, or thromboembolic phenomena elsewhere in the body.

Renal transplant abnormalities: *Renal artery stenosis* - vascular complications of renal transplants are seen in less than 10% of transplant recipients. Renal artery stenosis most commonly occurs within several centimeters of the anastomosis. Renal artery stenosis characterized by a high velocity jet (greater than 2 m/s) with distal turbulence. Tardus Parvus waveform (delayed upstroke in systole) in the intrarenal branches indicates the presence of a focal stenosis. *Renal artery occlusion* is easier to detect in transplants than

in native kidneys because there is no flow throughout the entire transplant. Transplant rejection - Normal transplants have a diastolic flow that is 30% to 50% of that of systole. During rejection, the vascular impedance increases, resulting in a decrease or even reversal of diastolic flow. Resistive index (RI) – is the most popular method of determining Doppler signals. The formula for computing the RI is as follows: RI= Max – Min/Max. An RI of 0.7 or less indicates good profusion, whereas an RI of 0.7 to 0.9 indicates possible rejection and over 0.9 indicates probable rejection.

SPLEEN AND RETROPERITONEUM



Physiology: It is composed of two components, red pulp and white pulp. *Red pulp* - acts as a filter, which aids in absorption of degenerating blood cells. *White pulp* - is composed of lymphoid tissues that produce lymphocytes. Splenic functional divisions can be divided into those related to the *reticuloendothelial* system and those related to its functions as an organ. Reticuloendothelial system produces lymphocytes, plasma cells, antibodies, and stores iron and metabolites. Organ related functions are as follows: red blood cell (erythrocyte) maturation, regulation of platelet and leukocyte life span, disposal of degenerating red blood cells. Storage – The spleen can store a lot of red blood cells due to its high smooth muscle content. Smooth muscle contraction causes the spleen to release blood cells into the body when necessary. If the number of cells stored becomes excessive, splenomegaly will develop.

Size of spleen: length varies, but its longest dimension, superior to inferior, should not exceed 13 cm. *Depth* – Anterior to posterior dimension should not exceed 8 cm.

Location of the spleen – lies in the left hypochondrium with its longest axis along the 10^{th} rib. Bordering structures are: anteromedial border – the tail of the pancreas, and the splenic flexure of the colon anteriorly. Posteroinferior border is the left kidney. Superior border is the diaphragm and lungs. Posterior border is the diaphragm, lungs, 9^{th}, 10^{th}, and 11^{th} ribs.

Gross anatomy – The spleen is a highly vascular mass of lymphoid tissue. It is ovoid with a convex superior surface and a concave inferior surface. It is covered almost

entirely by peritoneum except for the hilum where the vessels enter and leave. *Venous* – The splenic vein exits the hilum and courses medially to join the superior mesenteric vein, which makes up the portal confluence. *Arterial* – The splenic artery originates at the celiac trunk and often branches into two or more smaller arteries before entering the splenic hilum.

Sonographic appearance: the spleen appears homogeneous in texture. It is very smooth and medium gray in color. It should be the same or less echogenic than the liver. Echogenic reflections may be seen that represent calcifications of small arterial walls or calcified granulomatous inclusions (healed infection). It may be difficult to image due to bowel gas and to overlying ribs. It is often easier to image intercostally from a coronal approach.

Normal variants: The only significant normal variant is the *accessory spleen*, it is found in 10 % of the general population. These islands of tissue are usually located near the hilum or attached to the pancreatic tail.

Sonographic applications: Examinations of the spleen are indicated for history of trauma to rule out hemorrhage, for suspected enlargement or, to rule out masses.

Retroperitoneum will be briefly covered, but first, we need a quick review of the peritoneum. *Peritoneal cavity* - is the largest cavity; it encompasses the abdomen and pelvis. It is lined with a *peritoneal membrane (parietal)*. It is a thin sheet of tissue that secretes serous fluid. The fluid acts as a lubricant and facilitates free movement between organs. The cavity is a closed sac in males and almost completely closed in females except for the fallopian tubes. Intraperitoneal structures are lined with their own peritoneal membrane (visceral). The intraperitoneal structures are connected by the mesentery, which is a double fold of peritoneum that attaches to the abdominal wall. The intraperitoneal structures include the following: liver, gallbladder, spleen, stomach, the majority of the intestines, and the ovaries in females. Retroperitoneum - is a space located posterior to the peritoneum and has no visceral covering. It includes the following structures: kidneys and adrenal glands, pancreas, aorta, inferior vena cava, urinary bladder, ureters, if female-uterus, or male-prostate gland, and lymphatic system.

Sonographic appearance: of the peritoneum and retroperitoneum are not routinely visualized unless there is fluid or masses present. Most lymph nodes are not seen unless they enlarge due to infection or metastasis.

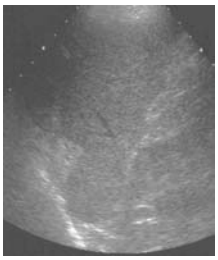
Sonographic Applications: the retroperitoneum is usually scanned for suspected masses or ascites (free fluid).

Patient preparation for abdominal ultrasound is nothing by mouth (NPO) after midnight the day prior to the exam.

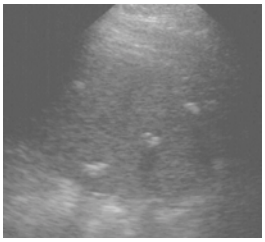
Hypersplenism: It is a complex symptom characterized by congestive splenomegaly, leukopenia, and anemia. Splenic involvement is thought to be the primary cause of this

disorder. Hyperslenic syndrome has been divided into primary and secondary types. Primary hypersplenism – is defined as increased splenic activity and size of unknown cause. Secondary hypersplenism – may occur in patients whose splenomegaly has a known origin, such as leukemia or lymphoma.

Diffuse disease:



Splenic infarction: It is the most common cause of focal lesions in the spleen. It occurs because of septic emboli and local thrombosis in patients with the following: Pancreatitis, subacute bacterial endocarditis, leukemia, lymphomatous disorders, sickle cell anemia, and sarcoidosis. **Sonographic appearance:** depends on the time of onset. Fresh hemorrhage has a hypoechoic appearance. Healed infarctions appear as echogenic peripheral wedge-shaped lesions with their base toward the subcapsular surface of the spleen. The infarctions may become nodular or hyperechoic with time.



Granulocytopoietic abnormalities: This includes cases of reaction hyperplasia resulting from acute or chronic infection (i.e., splenitis, sarcoid, tuberculosis). **Sonographic findings:** Splenomegaly is seen with a diffusely hypoechoic pattern (less dense than the liver). Patients who have been previous exposed to granulomatous infection present with bright echogenic lesions with or without shadowing.

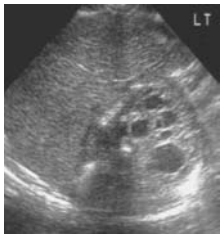
Splenic cysts: are classified as parasitic or nonparasitic in origin. **Parasitic cysts:** *Echinococcus* is the only parasite that forms splenic cysts; it is uncommon in the United States. **Nonparasitic cysts:** are categorized as either primary (true) or secondary (false). Primary (true) - they contain an epithelial lining and are considered to be congenital in origin. They occur more frequently in females; 50% occur in patients under 15 years of age. They are usually solitary and unilocular and rarely contain calcification. Secondary (false) - They lack a cellular lining, probably developing as a result of prior trauma to the spleen. They account for 80% of nonparasitic splenic cysts.

Trauma to the spleen: It is most commonly injured as a result of blunt abdominal trauma. If the patient has severe left upper quadrant pain secondary trauma, a splenic or subcapsular hematoma should be considered. Blunt trauma has two outcomes: If the capsule is intact, the outcome may be intraparenchymal or subcapsular hematoma. If the

capsule ruptures, a focal or free retroperitoneal hematoma may form. **Note:** In delayed ruptures, a subcapsular hematoma may develop with subsequent rupture. **Clinical findings:** Left upper quadrant pain, left flank pain, and dizziness. On clinical exam the patient may have tenderness over the left upper quadrant, hypotension, and decreased hemoglobin, which indicates a bleed. **Ultrasound findings:** The most prominent finding is splenomegaly, with progressive enlargement as the bleed continues. Irregular splenic border, hematoma, contusion (splenic inhomogeneity), subcapsular and pericapsular fluid collections, free intraperitoneal blood, or left pleural effusion may also be present. **Sonographic appearance of hemorrhage:** the sonographer must be aware that blood exhibits various echo patterns, depending on the time that has passed since the trauma. Fresh hemorrhage may appear hypoechoic and be difficult to distinguish from normal splenic tissue. **Note:** Look for the double-contour sign depicting the hematoma as separate from the spleen. As the protein and cells reabsorb the hematoma, it becomes organized and the fluid becomes hyperechoic similar to splenic tissue. With time, the hematoma becomes more fluid or lucent-appearing.

Primary tumors of the spleen: Generally speaking, primary tumors are very rare. **Note:** The benign and malignant tumors have a very similar appearance and they cannot be adequately differentiated with sonography. No specific tumors will be discussed because it is beyond the scope of this course. When one finds a complex mass in the spleen, it should be identified, and if possible, evaluated by other imaging modalities.

Adrenal pathology:



Adrenal cysts: They present a typical cystic pattern, as seen in other organs within the body, having a strong back wall, no internal echoes, and good through transmission. They have a tendency to become calcified, which gives them the ultrasound appearance of a somewhat solid mass with no internal echoes. When the cyst has hemorrhaged, it appears as a complex mass with multiple internal echoes and good through transmission.

Adrenal carcinoma: Most are not functional and have a varying appearance.

Adrenal neuroblastoma: It is the most common malignancy of the adrenal glands in childhood and the most common tumor of infancy. It generally arises from the adrenal medulla. Although children are mainly asymptomatic, some do present with a palpable abdominal mass that must be differentiated from a neonatal hemorrhage and hydronephrosis. Sonographically the tumor is an echogenic mass; it may also be large. **Note:** Evaluation of the surrounding retroperitoneum and liver should be made to rule out metastases.

Lymphadenopathy: There are two major lymph node–bearing areas in the retroperitoneal cavity: the iliac and hypogastric area within the pelvis and the paraortic group in the upper retroperitoneum. **Note:** Ultrasound evaluation of lymphadenopathy is usually limited to the paraortic group due to the small bowel obscuring the pelvis. Normal nodes are smaller than the tip of a finger, less than 1.5 cm, and are not usually seen with ultrasound. **Note:** However, if the nodes enlarge because of infection or tumor, they can easily be seen with ultrasound. Ultrasound evaluation of paraortic nodes **Sonographic appearance of abnormal nodes:** They are usually rounded, focal echo-poor lesions 1 to 3 cm in size. The larger nodes can compress organs and vessels, and even displace the kidney. Most of the nodes lie along the anterior margins of the aorta and IVC. **Scanning technique:** The nodes are usually located by scanning the aorta and IVC in the supine position. It is important to scan in two planes because the enlarged node may mimic an aneurysm or tumor in only one plane. If a node is suspected in an image, apply gentle pressure with the transducer to see if the mass changes shape or moves. **Note:** If the node changes shape or peristalsis is seen, it is most likely bowel.

Primary retroperitoneal tumors: They are defined as tumors that originate independently within the retroperitoneal space. The tumors can arise anywhere and are most likely malignant. Like other tumors, they exhibit a variety of sonographic patterns.

Neurogenic tumors: They are usually encountered in the paravertebral region, where they arise from nerve roots and sympathetic ganglia. **Sonographic appearance:** Their pattern is quite variable.

Fibrosarcomas and rhabdomyosarcomas: They may be quite invasive and infiltrate widely into muscles and adjoining soft tissues. They often present with extension across the midline and appear very similar to lymphomas. Sonographically, they are highly reflective tumors.

Teratomatous tumors: They arise from the upper peritoneum and the pelvis. They may contain calcified echoes from bones, cartilage, and teeth, as well as soft tissue elements.

Secondary retroperitoneal tumors: They are primarily recurrences from previous resected tumors in the abdomen. Recurrent masses from previous renal carcinoma are frequent. Ascitic fluid along with a retroperitoneal tumor, usually indicates seeding or invasion of the peritoneal surface. Evaluation of the paraortic region (for lymphadenopathy) and liver should be performed to detect metastatic involvement.

Retroperitoneal fluid collections:

Urinoma: It is defined as a walled-off collection of extravasated urine that develops spontaneously after trauma, surgery, or a subacute or chronic urinary obstruction. They usually collect about the kidney or upper ureter in the perinephric space. Occasionally urinomas dissect into the pelvis and compress the bladder. **Sonographic appearance:** They generally appear sonolucent unless they become infected.

Hemorrhage - A retroperitoneal hemorrhage can occur in a variety of conditions, including trauma, vasculitis, leaking aortic aneurysm, or bleeding neoplasm. Fresh hematomas present as sonolucent areas; whereas organized thrombus or clot formation show echo densities within the mass. **Note:** Calcification may be seen in longstanding hematomas.

Abscess: Its formation may result from surgery, trauma, or perforations of the bowel or duodenum. **Sonographic appearance:** The abscess usually has a more complex pattern with debris. The abscess frequently extends along or within the muscle planes. Gas, when it is present within the abscess, is reflective and casts an acoustic shadow. **Note:** The sonographer should be careful not to misdiagnose a gas-containing abscess for "bowel" patterns. It has an irregular shape, and lies in the most dependent portion of the retroperitoneal space.

STANDARD ABDOMINAL IMAGING:

Pancreas:

With the patient in the supine position, locate a window to image the pancreas. If the pancreas isn't visualized (typically due to inadequate patient preparation), take a representative image of the area. After the pancreas is located, begin surveying the pancreas in the transverse plane (longitudinal axis sweeping from superior to inferior) and then in the longitudinal plane (transverse axis sweeping from the patients right to their left). Obtain at least two transverse images of the pancreas. If entire pancreas cannot be visualized on one image, take three dedicated images of each pancreatic area documenting the head, body, and tail. If pancreatic pathology is suspected document head, body, and tail longitudinally.

Aorta:

After a quick survey of the aorta and common iliac arteries (longitudinal and transverse), begin your scan in the longitudinal axis with the proximal abdominal aorta. Obtain a longitudinal image of the proximal aorta with and without anterior-posterior measurements. Measure outer to outer wall in the widest proximal segment. Obtain a longitudinal image of the mid aorta with and without anterior-posterior measurements. Measure outer to outer wall just distal to the SMA. Obtain a longitudinal image of the distal aorta with and without anterior-posterior measurements. Measure outer to outer wall just proximal to the bifurcation. Obtain a longitudinal image of the proximal right common iliac artery (CIA) with and without anterior-posterior measurements. Measure outer to outer wall in the widest segment distal to the bifurcation. Obtain a longitudinal image of the proximal left common iliac artery (CIA) with and without anterior-posterior measurements. Measure outer to outer wall in the widest segment distal to the bifurcation. Aorta (Transverse) - begin your transverse scan of the proximal aorta at the xiphoid process. Obtain a transverse image of the proximal aorta with and without width measurements. Measure outer to outer wall in the widest proximal segment. Obtain a transverse image of the mid aorta with and without width measurements. Measure outer to outer wall where the transverse SMA is first visualized. Obtain a transverse image of the distal aorta with and without width measurements. Measure outer to outer wall just proximal to the bifurcation. Obtain a transverse image of the proximal common iliac

arteries (CIA) with and without width measurements. Measure outer to outer wall in the widest segments just distal to the bifurcation. Take individual images if CIAS are not visualized together on one image.

Liver:

With the patient in the supine position, locate and survey the entire liver longitudinally and transverse. Imaging ***left lobe of liver longitudinally*** - obtain an image of the left lobe of the liver closest to spleen, then moving toward the right side of the body image the left lobe and proximal aorta, the left lobe and caudate lobe with the IVC. Obtain an image of the right lobe including the portal vein. Imaging ***right lobe of liver longitudinally*** - Obtain an image of the right lobe to include the gallbladder, right lobe including the right kidney, and lateral right lobe. Imaging ***Left lobe of liver in transverse*** - Obtain a transverse image of the superior left lobe of the liver including the hepatic veins, left lobe including the portal veins, the left lobe and caudate lobe. Imaging ***right lobe of liver in transverse*** – moving transducer from superior to inferior liver: obtain a transverse image of the superior right lobe, right lobe including the hepatic veins, right lobe including the portal veins, and the inferior right lobe.

Gallbladder:

With the patient in the supine position, locate, and then survey the gallbladder first in the longitudinal axis and in the transverse axis. Obtain at least two images of the gallbladder longitudinally. If the entire gallbladder could not be visualized on one image document the three different areas - fundus, body, and neck. Obtain a transverse image of the gallbladder neck with the patient supine. Obtain a transverse image of the gallbladder body with and without anterior-posterior wall thickness measurements. Obtain a transverse image of the gallbladder fundus with the patient supine. Instruct the patient to move to the decubitus position and relocate the gallbladder. Survey the gallbladder in the longitudinal and transverse axis. **Note:** If stones or other pathology are visualized within the gallbladder, try to demonstrate movement by shifting the patient (decubitus, upright, etc.) and document any movement. Always annotate direction scanning (longitudinal, transverse, sagittal, coronal) and patient position (prone, sitting, supine, decubitus).

Biliary System:

With the patient still in the decubitus position, locate a quality window to image the CD and CBD. **Note:** If the CBD isn't seen, try rolling the patient back to the supine position. Start by surveying the CD, CBD and portal vein as far as it can be visualized from the most proximal area to the most distal area in longitudinal and transverse planes. Obtain an image of the common duct longitudinally with and without anterior-posterior measurements at the point where it travels over the transverse hepatic artery (utilize color doppler to confirm biliary system is being imaged, not hepatic arteries). Obtain an image of the common bile duct longitudinally with and without anterior-posterior measurements at the distal most area (preferably as it enter into the head of the pancreas) (again use color doppler to confirm biliary system is being imaged, not hepatic arteries).

Right kidney:

With the patient in the left lateral decubitus position, locate and survey the right kidney longitudinally and in the transverse axis. Obtain a longitudinal image of the right kidney lateral. Obtain a longitudinal image of the right kidney mid, with and without anterior-posterior and length measurements. Make sure you image the kidney in its longest dimension. Obtain a longitudinal image of the right kidney medial. Turn 90 degrees counter-clockwise from the mid kidney image to obtain a transverse image of the right kidney. Obtain a transverse image of the right kidney superiorly. Obtain a transverse image of the right kidney mid, with and without a width measurement. Obtain a transverse image of the right kidney inferiorly.

Left kidney:

With the patient in the right lateral decubitus position, locate and survey the left kidney longitudinally and in the transverse axis. Obtain a longitudinal image of the left kidney lateral. Obtain a longitudinal image of the left kidney mid, with and without anterior-posterior and length measurements. Make sure you image the kidney in its longest dimension. Obtain a longitudinal image of the left kidney medial. Turn 90 degrees counter-clockwise from the mid kidney image to obtain a transverse image of the left kidney. Obtain a transverse image of the left kidney superiorly. Obtain a transverse image of the left kidney mid, with and without a width measurement. Obtain a transverse image of the left kidney inferiorly. Obtain an image of the spleen and left kidney to compare echo textures.

Spleen:

With the patient in the right lateral decubitus position, locate and survey the spleen coronally and transverse. Obtain a coronal image of the spleen. Obtain a transverse image of the spleen.

Superficial Structures:

After locating any masses or superficial structures within the abdomen, survey longitudinally and in transverse axis. Obtain longitudinal images of the mass or superficial structure with and without length/width/height measurements. Use body marker or clock orientation as necessary. Obtain transverse images of the mass or superficial structure with and without width measurements. Again use body marker or clock orientation as necessary.

Quality control:

QC the films or computer based imaging and fill out appropriate forms before you show the study to your radiologist. Take additional views when requested.

VASCULAR SYSTEM

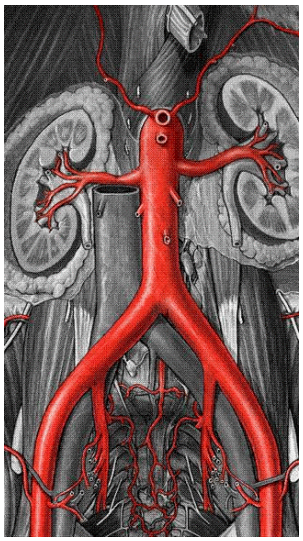
Abdominal Aorta:

The ***aorta*** is one of two great vessels in the body. Size depends on body habitus. The average is approximately **2 cm** at the most superior portion and narrows down to **1.5 cm** at the iliac bifurcation. The aorta should not exceed **3 cm** at any level.

Comprised of three layers

- **Tunica intima:** Innermost layer (elastic fibrous layer). Appears as a bright, echogenic line sonographically.
- **Tunica media:** middle layer (muscular layer). Appears anechoic sonographically.
- **Tunica adventitia:** Outermost layer. Appears as a moderately echogenic line sonographically.

Physiology: Aorta has two functions: 1) Carries oxygenated blood to organs throughout the body. 2) Plays a critical role in homeostasis (The maintenance of steady states in the organism by coordinated physiological processes.).



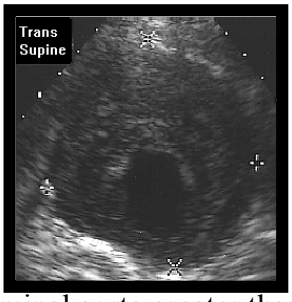
Location: Aorta is a retroperitoneal structure coursing in a superior-to-inferior direction along the left side of the spine. Originates from the heart at the left ventricle outflow tract and follows a candy cane-shaped loop into the thoracic cavity. **Note:** This portion is considered the thoracic aorta and is not visualized during an abdominal aorta sonogram. After the aorta passes through the diaphragm via the aorta hiatus, it is considered the **abdominal aorta**. It then continues to course inferiorly and ends at its bifurcation into the iliac arteries. The iliac arteries continue and bifurcate into the internal and external iliac arteries. **Note:** This is not part of the abdominal aorta. *Aortic branches*: Coursing from superior-to-inferior, the abdominal aorta has the following branches: *Celiac artery (CA)*: (axis or trunk) Originates around the level of the pancreas and branches into the common hepatic, splenic and lt. gastric arteries. The c*ommon hepatic artery* (CHA) courses laterally from the **CA** to the patient's rt. side and bifurcate into the proper hepatic artery and the gastroduodenal artery. **Note:** The proper hepatic artery feeds the liver and the GDA feeds the greater curvature of the stomach & also the

duodenum. The *splenic artery* (SA) courses laterally towards the patient's left side. **Note:** The SA feeds the left side of the stomach, spleen and pancreas. The left gastric artery (LGA) courses superiorly and to the left. **Note:** The left gastric artery is the primary artery that feeds the stomach. Superior mesenteric artery (SMA): Branches anterior-inferior from the aorta within centimeters of the celiac axis and gives off many branches which feed the small intestine, a portion of the colon, pancreatic head, and duodenal area. *Renal arteries* (RA): The right and left **RA** originates just distal to the SMA and extends laterally to feed the kidneys. *Gonadal arteries* (GA): Originate from the anterior aspect of the aorta and course inferiorly. The rt. and lt. **GA** feed the gonads *Inferior mesenteric artery* (IMA): Originates from the anterior aspect of the aorta distal to the gonadal arteries and courses inferiorly to feed the majority of the colon.

Sonographic Appearance: Arteries should normally display an anechoic center that may show movement from arterial pulsations. The walls should be less flexible than veins, which are very collapsible. The most commonly visualized abdominal arteries are as follows: *Celiac axis (CHA & SA)*: Is most easily seen in the transverse plane slightly superior to the pancreas. (Looks like a seagull) *SMA*: Can be identified in the longitudinal plane just distal to the celiac axis. *RAs*: Are best demonstrated in the transverse plane and appear as small-diameter curvilinear vessels branching laterally from the aorta. The right **RA** can also be visualized in the longitudinal plane coursing posterior to the inferior vena cava. *Common iliac arteries*: Are visualized at the level of the umbilicus. They are best demonstrated in the transverse plane and then each artery can be evaluated longitudinally. **Note:** The iliac arteries exist in an oblique axis from mid-line.

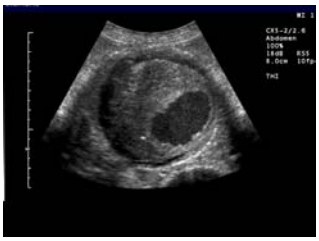
Sonographic Applications: The aorta and its branches are primarily evaluated to detect aneurysms and stenosis. Stenosis of the aortic branches is readily detected with doppler ultrasound. Stenosis is often a causative factor to symptoms such as bowel ischemia from stenosis.

Abdominal Aorta Pathology:

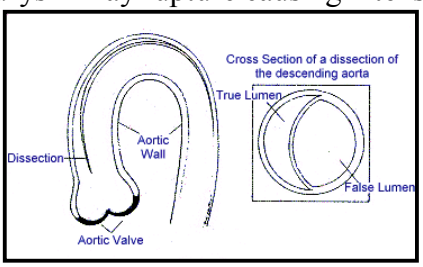


Aortic aneurysm: An abdominal aorta greater than 3 cm in diameter is considered abnormal. A focal enlargement beyond this limit is, by definition, an aneurysm. Three predisposed factors to aneurysm formation: arteriosclerosis, syphilis, and cystic medial necrosis. **Note:** Most abdominal aortic aneurysms are atherosclerotic in origin. Aortic aneurysms are found more often in middle-aged men than women. Most aortic aneurysms begin in the region of the bifurcation and propagate proximally; fewer than 10% involve the renal arteries. Extension into the common iliac arteries is common.

Most aortic aneurysms have a fusiform (tapering at both ends) shape. Although most are relatively symmetrical, tortuosity may make them appear asymmetric. Some are may appear saccular (pouch or sac-shaped) or cylindrical (rodlike) in nature.
Classifications of aneurysms: Fusiform aneurysms – the most common type located at the distal aorta near the bifurcation. **Saccular aneurysms** - They are more spherical (sac-like) and larger (5–10 cm) than the fusiform aneurysm. It may be partially or completely filled with thrombus. **Cylindrical aneurysms** - apparent when the aorta does not taper distally causing an abnormal, uniform dilation of the aorta. Sonographic evaluation - the AP diameter of the aneurysm must be measured on the sagittal view. A coronal view through left flank may afford better visualization of the aorta. Use the spleen and left kidney as a window to visualize the bifurcation. The sonographer must carefully follow the course of the aneurysm to separate it from a retroperitoneal mass or lymphadenopathy. Because the aneurysm may extend into the iliac arteries, the sonographer should examine the iliac arteries in at least two planes. **Note:** Normal iliac arteries should not measure over 1 cm. The relationship of the renal arteries to the aneurysm (longitudinal distance) should also be documented. **Note:** This information aids the surgeon if surgical correction becomes necessary. Most surgeons do not consider operating on patients with aneurysms less than 4-5 cm in maximum diameter. At 5 cm the incidence of spontaneous rupture begins to climb (to reach over75% at 7 cm). Generally, aneurysms increase in diameter at the rate of approximately 2 mm per year.

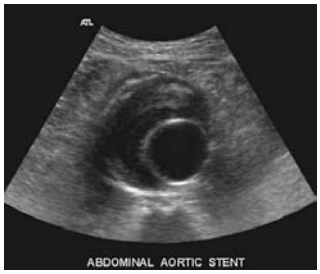


Thrombus: When an aneurysm is present, the presence of thrombus should be evaluated. Thrombus within an aneurysm displays medium to low-level echoes in the periphery of the lumen. Gain set too low may fail to identify thrombus. Adjust gain settings just below the level at which artifactual echoes appear in the IVC. Use Color Doppler to confirm or disprove the presence of thrombus. **Note:** The echoes should be seen in both planes on more than one scan to be separated from low-level reverberation echoes. Clinical symptoms - Symptoms may vary in the patient with an abdominal aneurysm. The enlarged vessel may produce symptoms by impinging on adjacent structures, or it may occlude a vessel by direct pressure or thrombus with resulting embolism. A large aneurysm may rupture causing intense back pain and a drop in hematocrit.



Aortic dissection: Dissection defined – The splitting of the media layer of the aorta, which leads to formation of a dissecting aneurysm. Typical patients are 40 to 60 years

old; males predominate over females. When the dissection develops, hemorrhage occurs between the middle and outer thirds of the media. When visible, dissection appears as an echogenic septum dividing the aortic lumen into two compartments, which may be equal or unequal in size. Doppler detection of flow in both lumina establishes the diagnosis of dissection. Dissection of the aorta may be secondary to: Cystic medial necrosis - weakening of the arterial wall. Marfan's syndrome - an inherited disease affecting many areas, especially the aorta causing abnormal dilation, weakened walls, and eventual dissection, rupture, or both. Hypertension – an increased tension or pressure (abnormally high blood pressure).



Aortic grafts: An abdominal aneurysm may be surgically repaired with a flexible graft material attached to the end of the remaining aorta. The synthetic material used for the graft produces bright echo reflections compared to those from normal aortic walls. After surgery, the attached walls may swell at the site of attachment and form another aneurysm or pseudoaneurysm.

Inferior Vena Cava (IVC)

IVC is the second great vessel of the abdomen. **Size:** The diameter varies with inspiration and during a Valsalva maneuver. Although the size varies, it is considered dilated if the diameter exceeds **3.7 cm**.

Gross Anatomy: In comparison with the walls of an artery, veins have the same number of layers, however, their tunica media is smaller and the composite wall is more flexible (Low-pressure system).

Physiology (two functions): 1) The IVC and its tributaries, like all veins, have the primary function of returning deoxygenated blood to the heart. 2) The IVC and most veins are composed of valves to prevent retrograde flow due to the low pressure of the system.

Location: The IVC is formed by the convergence of the common iliac veins at the level of the umbilicus. It continues to course superiorly through the retroperitoneum along the anterior aspect of the spine and to the rt. of the aorta. The IVC will continue to course superiorly converging with the following veins:

- ***Lumbar veins:*** Empty the posterior abdominal wall and attach bilaterally to the posterior wall of the IVC. There are many pairs within the abdomen.
- *Right gonadal vein:* Courses parallel with the **IVC** and empties into the anterior lateral aspect of the **IVC**.

- ***Renal veins:*** Empty the kidneys and are located bilaterally. The *left renal vein* passes over the anterior aspect of the aorta and posterior to the **SMA**. The lt. renal vein also receives the left gonadal vein. The *right renal vein* is much shorter than the left.
- ***Hepatic veins:*** There are commonly three hepatic veins, which drain the liver of deoxygenated blood. *Right hepatic vein*: Drains the rt. lobe of the liver. *Middle hepatic vein*: empties the rt. and medial lt. liver lobes. *Left hepatic vein*: Empties the lt. lobe of the liver.

Sonographic Appearance: Should display an anechoic center with a thin hyperechoic wall. It is most commonly visualized in the longitudinal plane. *Hepatic veins*: Located superiorly in the liver and look like "bunny ears" in the transverse plane. *Renal veins:* They are seen in the transverse axis as curvilinear structures extending from the kidneys. They are larger than the renal arteries. *Common iliac veins*: Are first recognized in the transverse axis at the level of the umbilicus.

Sonographic Applications: The **IVC** and its visible branches are primarily evaluated for interluminal thrombosis and tumor invasion.

Portal Venous System

Size: Normally less than **13 mm.**

Gross Anatomy: Contains the same cross section as a vein.

Physiology: The function of the portal vein is to deliver blood from the spleen and gastrointestinal system to the liver for metabolism and detoxification.

Location: Portal vein is formed by the confluence of the superior mesenteric vein (SMV) and the splenic vein. The vessels contained in the portal venous system are as follows:

- ***Splenic vein:*** Drains the spleen and courses lateral to medial directly posterior to the pancreas.
- ***Superior mesenteric vein (SMV):*** Drains the small intestine and portions of the large intestine via smaller branches. It courses inferior to superior.
- ***Inferior mesenteric vein (IMV):*** Drains the large intestine via small branches. It also courses inferior superiorly and dumps into the splenic vein.
- ***Main portal vein:*** Coursing from the portal confluence the main portal vein is formed, it then branches into the right and left portal vein. The liver is fed by these subdivisions.

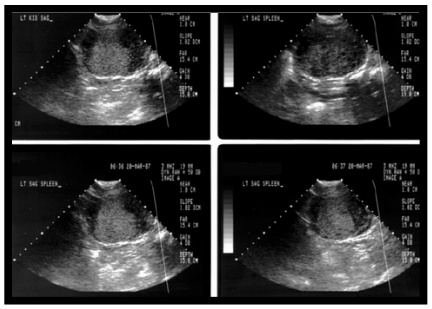
Sonographic Appearance: The portal vessels have a more echogenic wall when compared to the hepatic arteries and veins due to the portal vein's high collagen content in the walls. Left *portal vein:* Can be visualized entering the liver in the transverse

plane. *Right portal vein*: Can be found in an oblique orientation near the hilum of the right liver. This is also the general area for visualizing the common hepatic duct. *Main portal vein:* Can be visualized in the longitudinal axis just inferior to the right portal vein. *Portal confluence*: Can be visualized in the transverse plane posterior to the pancreatic head and is formed by the junction of the splenic vein and the SMV. *SMV*: Can be visualized in the longitudinal axis and appears as a more narrow continuation of the main portal vein. *Splenic vein:* Can be imaged in the transverse axis & is located posterior to the pancreatic body. *Portal Triad* – is the HA, common bile duct, and portal vein, they enters into the liver through the hilum or porta hepatus.

Sonographic Applications: It is primarily evaluated to detect thrombosis, tumor invasion, and portal venous hypertension via 2D imaging, color, and pulse wave doppler.

Inferior Vena Cava Pathology:

IVC dilatation: occurs in patients with right ventricular failure, hence the IVC does not collapse with expiration.



IVC tumor: The IVC can become obstructed by tumor formation. Sonographically it may show a spectrum of echotextures from echogenic to hypoechoic. It may extend from the lower extremities and pelvis. The most common tumor of the IVC is renal cell carcinoma (2% to 5%). Wilms' tumor and hepatocellular carcinoma have also been known to invade the IVC. In cases of IVC clot, examination of the renal veins is important to exclude secondary involvement.

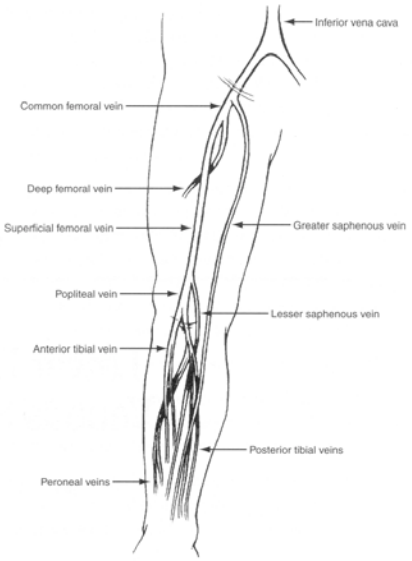
IVC Thrombosis: Complete thrombosis of the IVC is life threatening. Clinical symptoms include the following: leg edema, leg pain, lower back pain, pelvic pain, gastrointestinal complaints, and renal and liver abnormalities. Thrombosis within the IVC may appear as a spectrum of echotextures from echogenic to hypoechoic. Thrombus may extend from the lower extremities or pelvis. **Note:** Color doppler is useful to determine vessel occlusion. It is important to demonstrate tumor verses thrombus. Color flow Doppler will detect vessels in a tumor whereas the thrombus will not demonstrate vessels.

Renal Pathology:

Renal vein thrombosis: Ultrasound findings include the following: Direct visualization of thrombi in the renal vein and inferior vena cava. Demonstrated renal vein dilation proximal to the point of occlusion. The echodensity of the kidney may be altered with areas of increased and decreased echodensity from hemorrhage and edema. Increased renal size. Doppler shows decreased or no venous flow with arterial flow demonstrating

a narrow systolic peak and sharp reversal of diastolic flow. **Clinical signs:** are pain, nephromegaly, hematuria, or thromboembolic phenomena elsewhere in the body. Renal transplant abnormalities: Renal artery stenosis, Vascular complications of renal transplants are seen in less than 10% of transplant recipients. Renal artery stenosis most commonly occurs within several centimeters of the anastomosis. It is characterized by a high velocity jet (greater than 2 m/s) with distal turbulence. Tardus Parvus waveform (delayed upstroke in systole) in the intrarenal branches indicates the presence of a focal stenosis. Renal artery occlusion is easier to detect in transplants than in native kidneys because there is no flow throughout the entire transplant. Transplant rejection - Normal transplants have a diastolic flow that is 30% to 50% of that of systole. During rejection, the vascular impedance increases, resulting in a decrease or even reversal of diastolic flow. Resistive index (RI) is the most popular method of determining Doppler signals. The formula for computing the RI is as follows: RI= Max – Min/Max. An RI of 0.7 or less indicates good profusion, whereas an RI of 0.7 to 0.9 indicates possible rejection and over 0.9 indicates probable rejection.

Lower Extremity



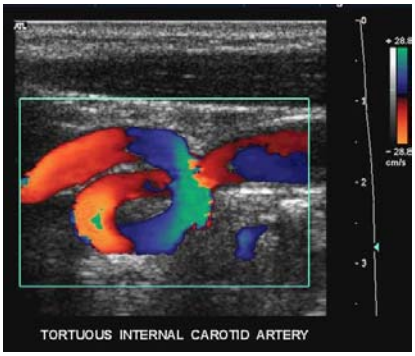
Anatomy - ***Inferior Vena Cava (IVC) and Iliac Veins:*** The deep veins of the lower extremity actually begin in the abdomen as the IVC and iliac veins. The IVC is formed by the two common iliac veins. The common iliac veins are formed at the junction of the internal and external iliac veins. The internal iliac veins drain the pelvic viscera and musculature. The external iliac veins drain the lower extremities. ***Femoral Venous System (Deep Veins):*** At the level of the inguinal ligament, the external iliac vein continues into the thigh as the common femoral vein. Slightly distal to this point the common femoral vein receives two branches: Superficial femoral vein or deep femoral vein. **Note:** Elevate the patient's head and torso (semi-erect) to distend the veins. ***Superficial Femoral Vein (Deep Vein):*** The superficial femoral vein continues through the thigh as the primary route of venous drainage. The superficial femoral vein is bifid in approximately 25% of individuals. Although this vessel is called the "Superficial" femoral vein, it is a part of the deep venous system. ***Popliteal and Calf Veins (Deep Veins):*** In the lower portion of the thigh, the superficial femoral vein dives into the adductor canal and becomes the popliteal vein. The popliteal vein circles around the

medial aspect of the thigh to the back of the knee, where it lies superficial to the popliteal artery. This superficial location is the inverse of that seen in the femoral area. Approximately 25% of popliteal veins are duplicated. The popliteal vein is formed at the confluence of the anterior tibial, posterior tibial, and peroneal veins, which drain the calf. Each of these systems consists of paired veins that accompany the artery of the same name. The posterior tibial and peroneal trunks unite in the upper portion of the calf or in the popliteal fossa to form the popliteal vein. The anterior tibial trunk has a unique anatomic configuration, in that it extends almost straight laterally from its junction with the popliteal vein. The paired anterior tibial veins often join the popliteal vein independently. ***Greater Saphenous Vein (Superficial Vein):*** The greater saphenous vein, also called the long saphenous vein, is the longest vein in the body. It joins the common femoral vein approximately 4 cm below the inguinal ligament, and extends along the medial aspect of the thigh and leg to the ankle. It then passes anterior to the medial malleolus and extends onto the foot. It functions to circumvent occlusion of the deep venous system. ***Lesser Saphenous Vein (Superficial Vein):*** The lesser, or small, saphenous vein empties into the popliteal vein posteriorly, in the popliteal space. It extends along the posterior aspect of the calf. ***Acute Venous Thrombosis:*** Acute venous thrombus is often hypoechoic on a gray-scale image. Distinct echogenic signals seen within a distended vein segment are a diagnostic criterion with a diagnostic sensitivity of approximately 50% for DVT. Loss of compressibility of the vein wall during the application of external pressure is the best-studied diagnostic criterion for acute DVT. Compression is applied in the transverse plane on the skin overlying the vein under study. The transducer is displayed over an increment of 1 to 2 cm, and compression is then applied to confirm compressibility. Pressure is then released, and the transducer is displaced again. This process is repeated along the course of the veins evaluated. Respiratory phasicity is normally confirmed by Doppler waveform analysis or color flow imaging. Loss of flow signals within the vein suggests complete thrombosis. False-positive results may occur when a more proximal obstruction such as extrinsic compression on the iliac vein, decreases venous return. Normal flow augmentation excludes the presence of a significant obstruction in the proximal veins, with the exception of well-developed collateral pathways or duplicated segments not involved with venous thrombosis. Although the presence of echogenic signals within a vein segment that is non-compressible supports the diagnosis of vein thrombosis, and the evaluation of flow signals with color flow imaging is complementary, loss of compressibility remains the most reliable diagnostic criterion. ***Chronic Venous Disease*** - Venous insufficiency (reflux) often follows an episode of acute DVT because the healing response to thrombus damages venous valves. Testing for reflux is done by: Performing a Valsalva maneuver or applying compression to the limb above the area evaluated. Inducing venous augmentation by squeezing the patient's calf while the patient is standing and then observing venous blood flow. Transient reversal of blood flow lasting less than 0.5 seconds is a normal physiologic response at the proximal common femoral vein and profunda femoral vein as well as in the popliteal vein. Prolonged reversal of blood flow lasting more than 0.5 seconds suggests venous insufficiency. Between 0.5 to 1.0 seconds, it is suggestive of venous insufficiency. Values above 1.0 second are definite evidence of venous insufficiency.

Acute vs. Chronic Disease: ***Acute*** - DVT tends to be located centrally in the vein lumen. The vein is usually large when thrombus is obstructing. A non-obstructing thrombus is surrounded by color flow signals. ***Chronic*** - DVT typically causes wall thickening or an eccentric soft tissue mass adherent to the vein wall. The vein is likely of normal caliber or small. Chronic thrombus tends to have homogeneous echoes that are isoechoic to anechoic. Color flow signals tend to be in the center of the vein lumen.

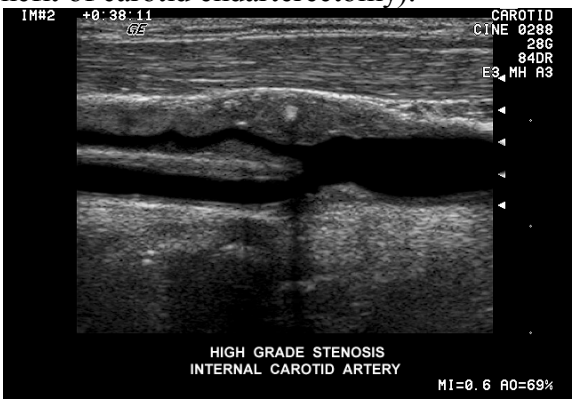
Carotid:

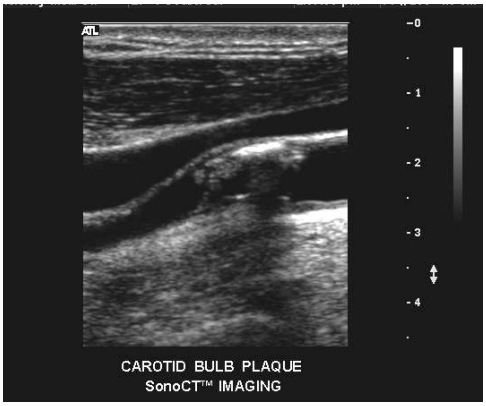
Aortic Arch The first major branch of the aortic arch is the innominate or brachocephalic artery, which divides into the right common carotid and subclavian arteries. The second major branch from the aortic arch is the left common carotid artery, which is usually separate from the third major branch, the left subclavian artery.
Common Carotid Arteries (CCA) - the CCAs ascend into the neck posterolateral to the thyroid gland and are located deep to the jugular vein and sternocleidomastoid muscles. The CCAs bifurcate at the upper margin of the thyroid cartilage into the external carotid artery and the internal carotid artery. **Note:** In people with short necks, the bifurcation may lie higher. ***Internal Carotid Arteries (ICA)*** - the ICA supplies blood to the brain and eyes. The ICA tends to be located more posteriorly and has no branches in the neck. The Ophthalmic artery is the first branch of the ICA The terminal branches of the ICA form the Circle of Willis. ***External carotid artery (ECA)*** - the ECA supplies blood to the face and scalp. The ECA usually passes anteromedial to the ICA and has multiple branches. The ECA is a smaller caliber vessel when compared to the ICA. ***Vertebral Artery (VA)*** - the vertebral artery supply blood to the posterior cranium. The VAs normally arises from the subclavian artery distal to the thyrocervical trunk. **Note:** The left vertebral artery originates directly from the aorta in 6% of patients. They course between the neural foramina from C2 through C6.They join at the base of the skull to form the basilar artery. ***Circle of Willis*** - the cerebral branches of the ICA and Vertebral arteries are joined at the base of the brain an arterial circle known as the Circle of Willis. This anastomosis is the most important element in the intracranial collateral circulation and is also a common site of aneurismal formation. In approximately 50% of the population, the Circle of Willis is incomplete and there are at least nine congenital variations. The most common anomalies involve the absence or hypoplasia of one or both communicating arteries.



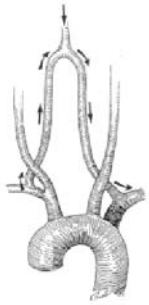
Anatomical Variations: Three anatomical variations can occur: 1) *Tortuosity* is the "S"-shaped curling in the course of the vessel. The patient is usually asymptomatic.
2) *Coiling* is an exaggerated tortuosity resulting in the vessel making a complete circle or loop. The patient is usually asymptomatic. 3) *Kinking* is a sharp angulation of the artery.

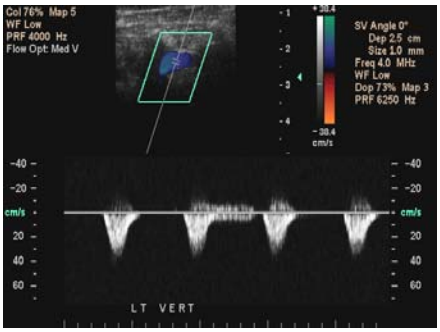
This causes narrowing of the vessel and is usually associated with stenosis. The patient is usually symptomatic. Indications: Symptomatic carotid stenosis, Cervical bruit, Follow-up progression of known atherosclerotic disease, To follow the results of prior carotid surgery or intervention, TIA or stroke. Diagnostic criteria - NASET Trial…a benchmark study on the use of carotid endarterectomy in North America (70% threshold - strong benefit of carotid endarterectomy).





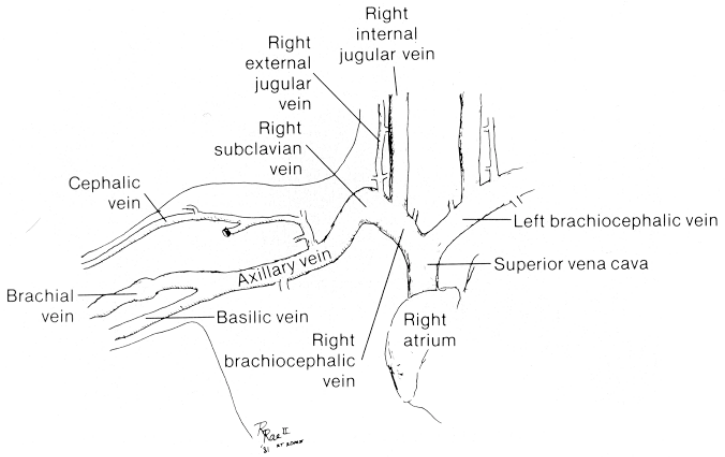
Plaque characterization: Density is relative to the strength of the echoes in the lesion in comparison to the nearby tissue. Different types of texture: *Homogeneous* – even distribution of echoes in the lesion. *Heterogeneous* – mixed areas with different echo strengths in the lesion. Surface **characteristics** are 1) *Smooth*- even, regular contour (without irregularities). 2) *Irregular*- jagged, irregular contour (not a smooth contour). 3) *Ulcerated*- defect of at least 2 mm. **Note:** Ulceration in a plaque could be the nucleus for the formation of embolic material that causes transient ischemic attacks (TIA) and strokes. ***Physiologic pitfalls:*** Low diastolic flow in ICA/ CCA - distal occlusions or high-grade stenosis often will cause a high-resistance flow pattern with little or no diastolic flow. High diastolic flow in ICA/ CCA – high-grade stenosis proximal to the area of insonation may cause dampened flow in the CCA/ICA. High diastolic flow in the ECA - recruitment of the ECA to provide flow to the internal circulation - termed internalization. Decreased velocity - overall low-amplitude, low-velocity ICA flow can occur in several situations. Cardiac arrhythmia is an irregular heart rate. Best value may be obtained by using a peak velocity from a beat immediately after a normal-length beat of 1 second. High velocity flow- at times, flow velocities appear elevated without evidence of substantial vascular disease. Contralateral stenosis - high-grade stenosis or occlusion in one carotid artery can significantly affect velocities in the contralateral vessel.





Subclavian Steal: diagnosed when reversed high-resistance vertebral artery flow is demonstrated on Spectral and Color Doppler. Technical errors and artifacts Grayscale errors in estimating stenosis - measurements of diameter and area stenosis should only be obtained in the transverse plane. Assigning angle theta - selecting an inaccurate Doppler angle correction is the most common error encountered in carotid ultrasonography.

Upper Extremity:



The prevalence of Upper Extremity DVT has increased, in part because of the widespread use of central venous catheters. Upper extremity deep venous thrombosis is associated with a higher morbidity and mortality than in the lower extremities. A non-invasive, relatively low cost examination for the diagnosis of UE DVT has therefore become increasingly important. Positioning - The patient's arm is positioned at approximately 45 degrees from the body, in a comfortable position. It is best to have the patient supine for maximum dilatation of the UE veins. ***Internal Jugular*** - Transverse compression is used throughout. Assess for thrombus or thickened walls consistent with prior thrombus. Spectral waveforms are assessed for transmitted cardiac pulsatility and respiratory variation. Monophasic flow that does not return to the baseline is abnormal. It indicates a more proximal stenosis i.e. Superior Vena Cava. ***Subclavian Vein*** - Can be the most difficult to evaluate. Compression of the medial segment is usually not possible. Thus, careful attention to the luminal diameter is necessary. It should be roughly similar to the adjacent subclavian artery; color flow imaging is used to assess the lumen for thrombus. Spectral waveforms are assessed for transmitted cardiac pulsatility and respiratory variation. Monophasic flow that does not return to the baseline is abnormal, it probably indicates clot more in the proximal circulation. Findings suggestive of ***vein stenosis*** include small diameter vein, multiple small venous vessels in the area (probable collaterals), a tortuous vessel and vein not in direct proximity to the artery. Deep inspiration, sniff and are performed for additional indirect assessment of the presence of a central venous abnormality. **Note:** When doing a longitudinal view it is immediately inferior to subclavian artery. ***Axillary Vein*** – The lateral subclavian vein may be followed into the axillary vein in the axilla. Have the patient abduct his/her arm to 90 degrees. Compression techniques can exclude thrombus in the vein. Be careful…. occasionally, the axillary vein will be completely occluded, and flow in an enlarged

cephalic vein can be mistaken for the axillary vein. Remember the cephalic vein is a superficial vein and will not have an accompanying artery. ***Brachial Veins*** - The brachial veins are paired veins, which run parallel to the brachial artery. The brachial veins are the only deep veins of the upper arm. Make sure to visualize both veins!! Use the compression technique. ***Basilic Vein*** - the basilic vein is a superficial vein that runs medial to the paired brachial veins in the caudal upper arm. It is the largest vein in the upper extremity. Use the compression technique. ***Cephalic Vein*** - The cephalic vein is a superficial vein that runs in the lateral superficial soft tissues. It is usually within the first centimeter of the skin. Use a light touch for this one. Typically look for the cephalic vein at its insertion sight within the lateral two thirds of the subclavian vein. The proximal portion is the most important to visualize.

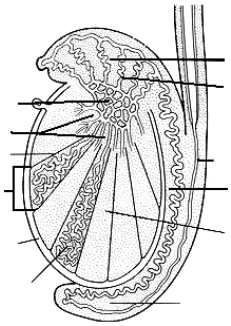
SMALL PARTS

SCROTUM

Physiology: Scrotum– is a sac of cutaneous tissue that supports the testicles, or testes which are the male reproductive organs. Testes– are the male gonads and are classified as both endocrine and exocrine glands. Endocrine– They produce testosterone, which is necessary for male characteristics. Exocrine– They produce sperm, which is transported and stored through a network of ducts which eventually becomes the epididymis.

Location: Scrotum - It is a pouch of skin that is continuous with the abdomen. It is suspended from the base of the male pelvis between the perineum and the penis. It contains the testes, epididymis, and the proximal portion of the ductus deferens (also called vas deferens). It contains the testes, epididymis, and the proximal portion of the ductus deferens (also called vas deferens). **Epididymis** - It is connected to the superior portion of the testis and runs along the posterior aspect to the base of the testis. It drains into the ductus deferens at the base of the testis. **Ductus deferens** - It courses superiorly and exits the scrotum through the inguinal canal. Once inside the abdominal cavity, each ductus deferens courses along the urinary bladder and turns medially and posteriorly and connects with the seminal vesicles to form the ejaculatory duct.

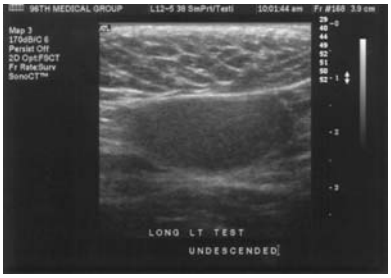
Size: Length =3 to 5 cm, AP = 2 to 3 cm, Width = 2 to 3 cm



Gross Anatomy: Scrotum - Externally–it is divided into lateral portions by a median ridge called the raphe. Internally–it is divided into sacs by a septum which is called the dartos or tunica dartos. **Cremaster muscle** - It surrounds each testicle and extends into the abdomen over the spermatic cord. Its contraction and relaxation regulates the internal temperature of the testicles. **Testis -** Tunica albuginea - It is a dense, white fibrous tissue that covers each testicle. It extends into the posterior wall of the testicle and forms the mediastinum testis. It is composed of 200 to 300 separate lobules. Each lobule contains one to three convoluted seminiferous tubules which actually produce the sperm. Seminiferous tubules– empty the sperm into the into the straight tubules, which lead to a network of ducts called the rete testis. Rete testis– is located within the mediastinum testis. The sperm exits the mediastinum testis through a series of coiled efferent ducts. Epididymis - It is composed mostly of a single convoluted tube called the ductus epididymis. Ductus epididymis– is composed of a head, body and tail. Ductus (vas) deferens– is the thicker, less convoluted continuation of the ductus epididymis.

Sonographic appearance: homogeneous, containing medium-level echoes similar in ultrasound appearance to the thyroid gland. Mediastinum testis– displays a highly echogenic line across the long axis of the testis. The testicles should have even echogenicity bilaterally when compared to each other.

Testicular Pathology:

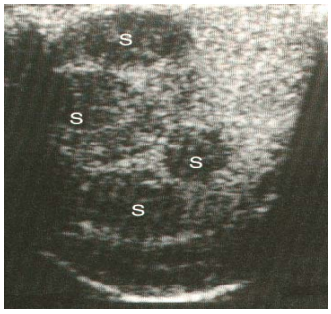


Undescended testicle:

The testes are formed in the retroperitoneum of a male fetus. The testes then descend into the scrotum via the inguinal canal shortly before birth (usually 28-32 weeks) or early in the neonatal period. Factors that can interrupt the descent of the testes: a deficiency of gonadotropin hormonal stimulation, physical factors such as adhesions or anatomical maldevelopments. The undescended testicle can be found in the following areas: Inguinal canal (80% of patients), occasionally in the intrabdominal area, or femoral area. **Sonographically:** the testicle appears ovoid in shape, smaller, and more hypoechoic than that of a normal testicle. Surgery is needed to correct an undescended testicle. **Note:** If surgery is not performed at an early age, the testis becomes atrophic and is at a high risk for cancer.

Malignant testicular tumors:

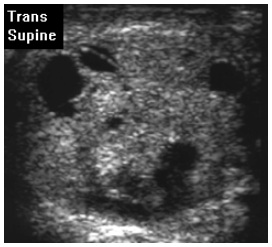
It occurs in young men between the ages of 15-45, in which 10% to 50% present with scrotal pain. Approximately 90% of primary testicular neoplasms are of germ cell origin. **Ultrasound evaluation:** Ultrasound is very sensitive for detecting testicular masses. Sonography can determine if the mass is intratesticular or extratesticular. **Note:** This is very important because most intratesticular masses are malignant and most extratesticular masses are benign although some primary and metastatic neoplasms may originate in the extratesticular structure. Although testicular masses can be well described and differentiated using ultrasound, it cannot absolutely confirm that an intratesticular mass is malignant. Malignant tumors appear on ultrasound as well-defined masses and are hypoechoic, although they can be heterogeneous. They may have both solid and cystic components, or they may at first appear solid, then develop an acute hemorrhage and appear cystic.



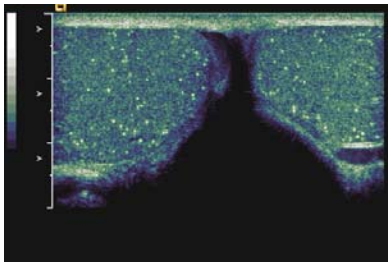
Seminoma: is the most common germinal tumor and most patients are 30 – 50 years old. It spreads via the lymphatics and is very radiosensitive. When compared to the other testicular malignancies, seminomas have the best prognosis.

Embryonal cell tumors: are less common, but are much more aggressive and lethal than seminomas. The 25-35 year age group is most susceptible. They spread through the blood and via the lymph nodes. **Choriocarcinoma** is a rare primary malignancy of the testis. It often presents itself as a small nodule, often with no testicular enlargement. This mass may have cystic areas as a result of hemorrhage and necrosis.

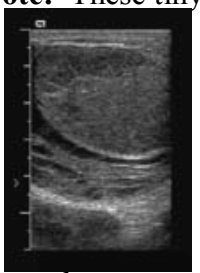
Benign testicular tumors:



Cysts: They present with well-rounded borders, anechoic, with posterior enhancement. They are considered rare processes, but are now more common than once thought due to the use of high frequency transducers.



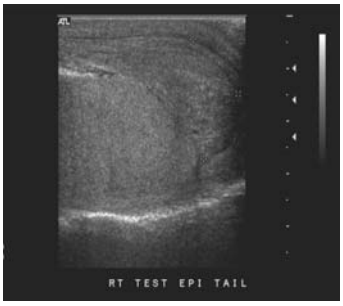
Microlithiasis: is defined as testicles with multiple tiny calcifications within their parenchyma. It has been seen in normal patients, but is associated with tumors, sterility, and cryptorchidism. Sonographically, they appear as multiple echogenic nonshadowing areas throughout the testis. **Note:** These tiny calcifications may obscure pathology.



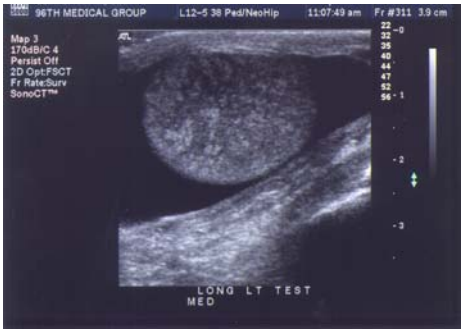
Torsion: The testicle attaches to the scrotum at the bare area. If the bare area is small, a small remnant stalk of tunica vaginalis allows the testicle to be mobile. Torsion occurs when the testicle revolves one or more times around this short stalk, which obstructs

blood flow to the testicle and results in severe pain. Torsion is more common in males between the ages of 12-18 years. Torsion is as common among men in there twenties as among prepubertal boys. Torsion needs to be diagnosed within the first few hours of onset or the testicle will not be salvageable by manual manipulation or surgery.
Note: Color Doppler sonography is highly effective in diagnosing torsion.
Sonographic appearance: Acute torsion occurs when the torsion is less than 24 hours old. The real-time ultrasound image is normal. The color and pulsed Doppler is abnormal (absence of flow in then testicle). Variable amounts of peritesticular fluid and scrotal wall thickening are usually observed. Subacute torsion occurs from 1 - 10 days after onset. The torsed testicle appears enlarged and hypoechoic, or may be normal in size. The testicle may have some inhomogeneity resulting from hemorrhage. Other findings include enlargement of the epididymis, a reactive hydrocele, and scrotal wall thickening. As in early phase of torsion, Doppler demonstrates absence of flow within the testicle.

Infections:

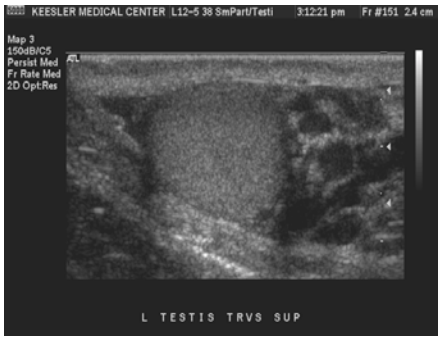


Epididymitis: The scrotum becomes swollen and tender. In most cases it is unilateral. The patient presents with a fever and painful urination. Infection usually begins in the epididymis and spreads to the testicle. Severe infection can lead to abscess formation in the epididymis or testicle. **Sonographic appearance:** It shows enlargement of the epididymal head, with decreased echogenicity secondary to edema. A reactive hydrocele may be present. Color doppler findings include an increased amount of flow in and around the epididymis. f an abscess is formed, complex cystic areas may be identified within the epididymis.

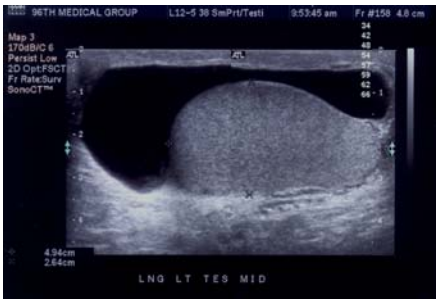


Orchitis: occurs when the infection spreads to the testicle. The testicle may appear normal or enlarged in size. The echogenicity may be decreased or heterogeneous. Reactive hydroceles and skin thickening are associated with orchitis. Color Doppler findings show increased testicular flow. **Chronic orchitis:** appears as layers of heterogeneous testicular parenchyma. **Focal orchitis:** occurs without involvement of the epididymis and has the same appearance as a neoplasm. It cannot be distinguished from

neoplasm, although clinical symptoms, such as fever and an increased white blood count, strongly suggest an infectious process.

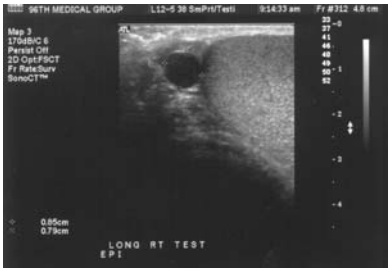


Varicocele: is an abnormal dilation and tortuosity of the veins in the pampiniform plexus of the spermatic cord. They are common on the left but can occur bilaterally. The right internal spermatic vein drains directly into the IVC. They mostly involve the left side, a finding attributed to the drainage pattern of the more tortuous left internal spermatic vein into the left renal vein. **Note:** 99% of varicoceles located on the left side. They may cause infertility because they are associated with a low sperm counts and decreased motility. The most obvious clinical sign is the "bag of worms" texture found during the physical exam. **Ultrasound findings:** Having the patient perform the Valsalva maneuver or stand may increase the size of the varicoceles making them more obvious. Blood flow is present and can be reversed but failure to detect flow cannot exclude diagnosis of a varicocele.



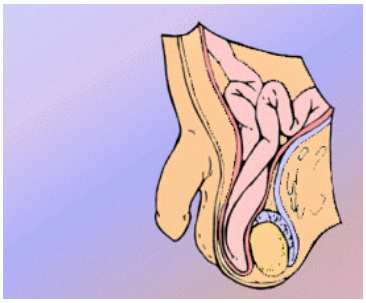
Hydrocele: Normally there are only a few drops of fluid between the parietal and visceral layers of the scrotum. A hydrocele is present when there is a larger collection of fluid within the scrotum. They can be congenital, idiopathic, or acquired. Hydrocele is the most common cause of scrotal swelling and it may be unilateral or bilateral. Its quantity varies from a few cubic centimeters to as much as liter. Acquired hydroceles are the result of infarction, inflammation, neoplasm, or trauma. **Sonographically**, they appear as anechoic fluid in the scrotum surrounding the testicle and epididymis. Occasionally, small particles and septations may be seen in the fluid. If the fluid contains blood, it is called a hematocele (fresh clot would appear mildly echogenic). If the fluid contains pus, it is called a pyocele.

Spermatoceles/Epdidymal cysts:



Spermatoceles: are benign cysts consisting of nonviable sperm. They represent 25% of epididymal cysts. They are commonly located in the epididymal head, but have been found in the body and tail. **Ultrasound appearance:** They appear as an anechoic cysts, with posterior enhance well-defined walls. Septations have been seen and spermatoceles can be singular or multiple. All epididymal cysts have a similar appearance, but spermatoceles occasionally contain internal echoes.

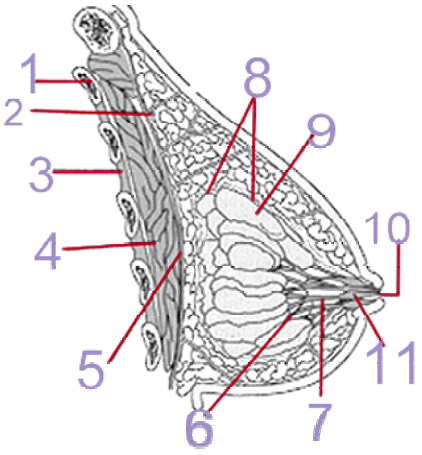
Epididymal cysts: cannot be differentiated from a spermatocele. They are composed of clear serous fluid, not sperm, and are much less common than spermatoceles.



Hernia: Scrotal hernia occurs when a section of bowel herniates through the patent processus vaginalis in the scrotum. The patient clinically presents with scrotal enlargement. Ultrasound can be used to diagnose hernia by demonstrating peristalsing loops of bowel in the scrotum.

Trauma: In cases of scrotal trauma, ultrasound can be helpful in evaluating the extent of the injury. Testicular parenchymal injury or hemorrhage can alter the normal homogeneous appearance of the testicle. **Sonographic appearance of scrotal hematomas:** are located in the epididymis or scrotal wall, they have variable sonographic appearances. Like hematomas in other parts of the body, the appearance is dependant on the age of the hematoma. The first appearance of a hematoma is hypoechoic. As the hematoma ages, its appearance becomes more echogenic.

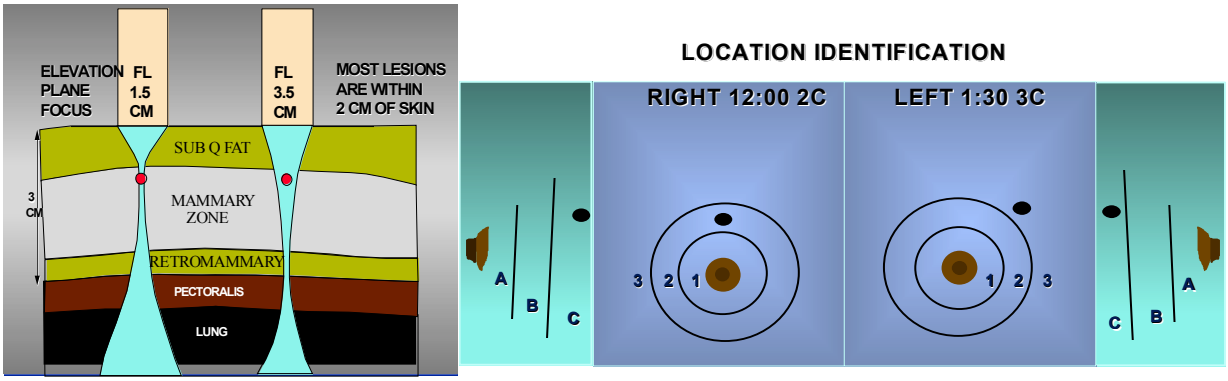
BREAST



Gross Anatomy: The breast is composed of parenchymal and stromal elements**.** Parenchymal elements– include the lobes, lobules, and ducts. Stromal elements– include all of the connective tissue and fat. The breast is composed of three layers. *Subcutaneous layer*– contains the skin, connective tissue, and all the subcutaneous fat. *Mammary layer*– contains the glandular tissues, ducts, and connective tissues. *Retromammary layer*– contains the retromammary fat and deep connective tissues. Glandular division: The normal breast is composed of 15 to 20 lobes separated by adipose tissue. Each lobe has an external drainage pathway into the nipple. The lobes are further divided into lobules, each of which contains glandular tissue elements called the alveoli (also called acini). Support– of breast tissue is provided by the *suspensory ligaments of Cooper*, which run between each two lobules from the deep muscle fascia to the skin surface.

Physiology: Breast development - Estrogen stimulates the development of stromal and parenchymal elements throughout the breast. Glandular tissues of the breast become active due to hormone stimulation during pregnancy. Milk production - The production of milk and its absence is controlled by hormones produced by the hypothalamus and anterior pituitary gland. Hypothalamus – produces prolactin-inhibiting factor, which prevents the release of prolactin until milk production becomes necessary following childbirth. Anterior pituitary gland – Following childbirth it releases prolactin , which stimulates development of the secretory system of the breast. After the placenta has been expelled and estrogen levels decrease, the prolactin levels will increase to a level which allows milk production. The infants suckling stimulates the secretion of ***oxytocin*** from the posterior pituitary gland, which causes the contraction of the lactiferous ducts and lactation begins. Glandular function - Alveoli– functions to secrete milk into the secondary tubules. Secondary tubules– from each lobule converge to form the ***lactiferous duct***. Each lactiferous duct has an ampulla or expanded region which is located near the nipple. The ampulla store the milk until it is released by suckling. Montgomery's gland (located on the areolae of the breast) secretes a lubricant to protect the breast from infection and trauma during breast feeding. Secretions from these glands keep the nipple pliant.

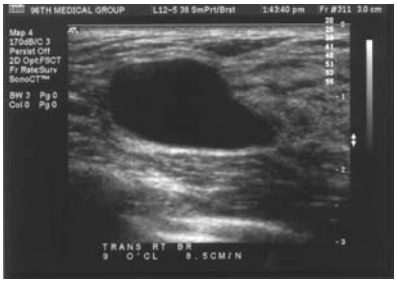
Size: It varies depending on the age, functional state, and the amount and arrangement of stromal and parenchymal elements of the breast. Breast development increases its size during puberty due to the stimulation of estrogen. Estrogen also increases breast size during childbearing years and with pregnancy. Decreased hormone stimulation after menopause causes the normal breast to atrophy.



Sonographic Appearance: Its appearance is dependent on several factors, primarily the age of the woman and the functional state of the breast. Younger breast tissue: It has a higher percentage of parenchyma compared with the percentage of fat within the breast. This high percentage of parenchymal tissue causes the breast to become more dense. With age, breast tissue becomes replaced with fatty tissues, which causes the subcutaneous layer to become more prominent as the mammary layer atrophies and occupies a smaller space. Breast tissue is visualized as three distinct layers: *Subcutaneous layer*– is the most anterior layer which contains the skin, the most anterior connective tissue components, and fat lobules. *Mammary layer*– is the middle layer that contains the breast parenchyma. Fat is usually seen within the parenchymal elements. Retromammary layer– is the most posterior layer, which contains fat lobules and the deeper connective tissue components. This layer is bordered posteriorly by the pectoralis major muscle group. Fat components– appear less echogenic than surrounding parenchymal breast tissue. Breast ducts and ductules– appear as echolucent tubular structures. Cooper's ligaments– and other fibrous components demonstrate increased echogenicity and are seen as bright linear echoes. Glandular or parenchymal tissues– tend to appear homogeneous in texture with medium to low-level echogenicity. Nipple– casts a shadow posteriorly when scanned.

Differential diagnosis of breast masses - Symptoms of breast masses include the following: Pain, Palpable mass, Spontaneous or induced nipple discharge, Skin dimpling, Ulceration, Nipple retraction. **Benign masses are usually associated with the following:** Pain and Nipple discharge. **Patients with cancer usually have the following:** Skin dimpling or ulceration, and nipple retraction.

Solid tumors:
Benign solid masses– are rubbery, mobile, and well delineated as seen in a fibroadenoma.
Malignant solid masses– are stone hard and irregular.
Soft tumors– usually represent a lipoma (fat tissue).

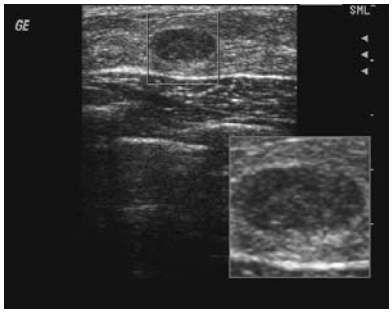


Cystic masses– are like a balloon of water, well delineated but not as mobile as fibroadenomas.

Benign Cystic disease:

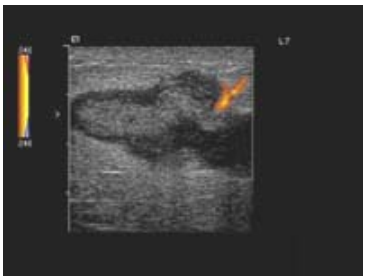
Clinical findings: It is commonly found in women 35 to 55 years of age. The cysts can be multiple or solitary and can become quite large. **Mammographic findings:** Usually smooth walled with sharp borders. A cyst and noncalcified fibroadenoma are hard to differentiate. Lucent rim of fat around cyst. **Ultrasound findings:** Smooth, sharp, well-defined borders, anechoic, posterior enhancement, lateral edge shadowing.

Fibrocystic disease – is defined as a disease which produces histologic changes in the terminal ducts and lobules of the breast in both the epithelial and the connective tissue. **Note:** It is usually accompanied by pain in the breast. **Clinical findings:** are pain, nodularity, a dominant mass, cysts, and occasional nipple discharge. **Mammographic findings:** Scattered fine, coarse, round, or lobulated densities with proliferation of parenchyma and linear strands of fibrous (stromal) tissue. **Ultrasound findings:** Average amount of subcutaneous fat. Areas of fibrous stroma that appear brighter than parenchyma. Small cysts scattered throughout the breast (cystic stage). Large cysts may also be present.



Fibroadenoma: is one of the most common benign breast tumors, the most common in childhood, and occurs primarily in young adult women. It may be found in one breast or bilaterally. Its growth is stimulated by the administration of estrogen. **Clinical findings:** Firm, rubbery, freely mobile, and clearly delineated from surrounding breast tissue. It is round or ovoid, smooth or lobulated. **Mammographic findings:** Smooth contour, difficult to differentiate from cyst. May contain calcium deposits, which make differential diagnosis easier; as degeneration of tumor progresses, size and number of deposits increase. **Ultrasound findings:** Smooth or lobulated borders, strong anterior wall, intermediate posterior enhancement, low-level homogeneous internal echoes.

Fat necrosis - may be caused by trauma to the breast or plasma cell mastitis, or from another disease present in the breast. It is more frequently found in older women. **Clinical findings:** Palpation reveals a spherical nodule that is generally superficial under a layer of calcified necrosis. **Mammographic findings:** show an area of nodular fibrosis or typical linear cyst-like calcifications. **Ultrasound findings:** Irregular complex mass with low-level echoes. May mimic a malignant lesion. May appear as fat, but is separate and different from the rest of the breast parenchyma.

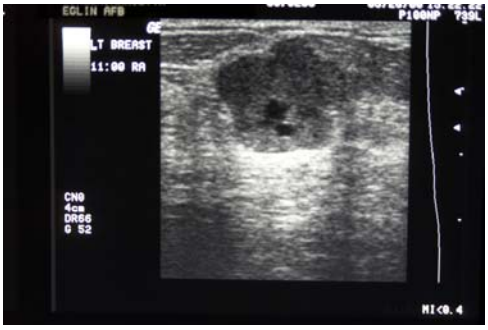


Abscess: may be single or multiple. A definite diagnosis cannot be made by mammogram alone; aspiration is needed. **Clinical findings:** are pain, swelling, and reddening of the overlying skin. **Note:** Swollen axillary nodes may also be present. **Ultrasound findings:** Diffuse mottled appearance of the breast, dense breast, irregular borders (some may be smooth), posterior enhancement, may have low-level internal echoes.

Malignant disease

Since many malignant breast masses appear similar, the only true way to diagnose a suspected malignant mass is to biopsy it. For this reason, specific types of malignancies will not be discussed. However, emphasis will be placed on the characteristics of a malignant mass instead. Cancer of the breast is of two types: sarcoma and carcinoma.

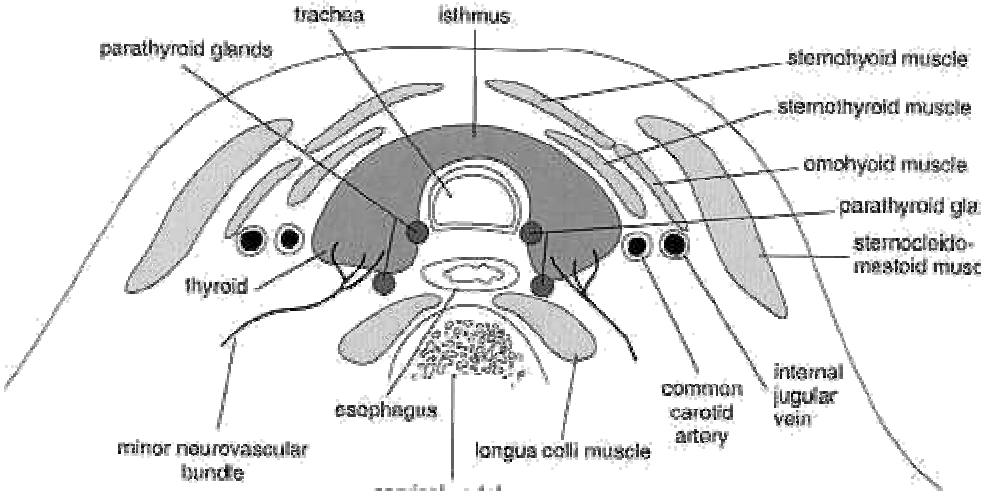
Sarcoma: refers to breast tumors that arise from the supporting or connective tissues. It is extremely uncommon, constituting less than 1% of all malignant breast tumors. It rapidly grows and invades fibrous tissue.



Carcinoma: refers to tumors that arise from the epithelium, in ductal or glandular tissue. It usually has tentacles. Carcinoma can be further classified as infiltrating and noninfiltrating. **Infiltrating carcinoma** has infiltrated the tissue beyond the basement membrane and into adjacent tissue. **Note:** Chances of metastases are enhanced with the time and type of growth present. The most common type of infiltrating carcinoma is the infiltrating ductal carcinoma with productive fibrosis (80% of carcinomas). **Noninfiltrating carcinoma** is a carcinoma of the lactiferous ducts that has not infiltrated the basement membrane but is proliferating within the confines of the ducts and their branches. There is no danger of metastases under these circumstances. The exact type of tumor can be determined only by a histological diagnosis, not by other noninvasive means. The role of ultrasound is to detect the mass and sonographically characterize it. **Note:** This information will aid the radiologist in diagnosing the suspected area when it is coupled with mammography. The most common **sonographic characteristics** of a **malignant** mass are as follows: Irregular spiculated contour or margins, round or

lobulated, intermediate anterior, and absent or weak posterior boundary echoes with great attenuation effects. The suspected mass is taller than wide.

THYROID AND PARATHYROID GLAND



Gross Anatomy: The gland is composed of right and left lobes connected by an isthmus. It is comprised of two thin layers of connective tissue. The pretracheal fascia, or false thyroid capsule, surrounds the gland. The true thyroid capsule is adherent to the gland surface.

Size: Length = 4 to 6 cm, AP diameter = 2 to 3 cm, Width 1.5 to 2 cm, Isthmus AP diameter = 2 to 6 mm

Physiology: The thyroid is an endocrine gland that plays a major role in growth and development. It indirectly regulates basal metabolism by the synthesis, storage, and secretion of thyroid hormones.

Sonographic Appearance: Normal thyroid parenchyma appears sonographically as a homogeneous gland of medium- to high-level echoes. Muscles– The neck muscles are hypoechoic relative to the thyroid gland.

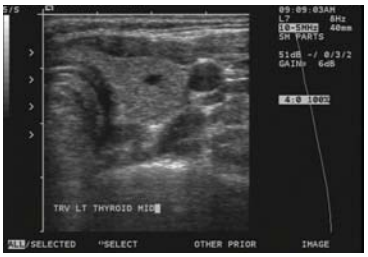
Parathyroid glands: They are usually located on the posterior medial surface of the thyroid gland. Most people have four glands but to have three to five parathyroid glands is not uncommon. The glands have been found in many different places such as in the neck or mediastinum. Each gland is flat and disc shaped with an echotexture similar to the thyroid gland. Normal glands-individually measure less than 4mm. Enlarged glands (>5mm)– have a decreased echotexture and appear sonographically as elongated masses between the longus colli muscle and the thyroid lobe.

Thyroid disease: The most common cause of thyroid disorders worldwide is iodine deficiency, which leads to goiter formation and hypothyroidism. In areas not deficient in iodine, autoimmune processes are believed to be the basis for most cases of thyroid disease.

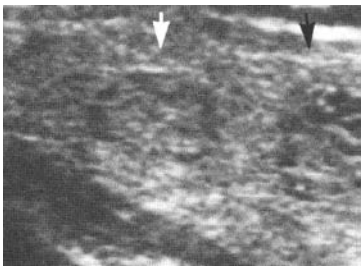
Goiter: Is defined as enlargement of the thyroid gland. It is the most common type of thyroid abnormality. Nodular hyperplasia, multinodular goiter, and adenomatous hyperplasia are some terms used to describe goiter. Goiters can be diffuse and symmetric

or irregular and nodular. **Sonographically:** the goiterous gland is usually enlarged, nodular, and sometimes inhomogeneous.

Benign thyroid lesions:



Cysts: Are thought to represent cystic degeneration of a follicular adenoma. Approximately 20% of solitary nodules are cystic. Blood or debris may be present in them. On ultrasound, they should have all the sonographic characteristics of a simple cyst, which are: Anechoic with sharply defined walls, Distal acoustic enhancement, Free of internal echoes, and Well-defined posterior interface.



Adenoma: is described as a benign thyroid neoplasm characterized by complete fibrous encapsulation. **Sonographic appearance:** They have a broad spectrum of sonographic appearances. Their sonographic hallmark is usually a sonolucent halo, which surrounds the lesion. Calcification, characteristically rim-like, can also be associated with adenomas.

Diffuse nontoxic goiter (colloid goiter): it occurs as a compensatory enlargement of the gland resulting from thyroid hormone deficiency. The gland becomes diffusely enlarged In the first stage, hyperplasia occurs; in the second stage, colloid involution. Progression of this process usually leads to an asymmetric and multinodular gland.

Adenomatous hyperplasia: Nodularity of the gland can be the end stage of diffuse nontoxic goiter. This end stage can be followed by focal scarring, focal areas of ischemia, and necrosis and cyst formation. **Sonographic appearance:** Lesions in multinodular goiter have many features of true adenomas. **Note:** The multiple nodules may demonstrate halos and may have clear or nondiscrete borders. Calcifications and cystic areas may be present within the nodules.

Thyroiditis: causes swelling and tenderness of the thyroid. It is caused by infection or can be related to autoimmune abnormalities. There are many forms of thyroiditis. The most common goiterous form of autoimmune thyroiditis is called Hashimoto's thyroiditis. **Sonographic appearance:** The gland appears enlarged and hypoechoic.

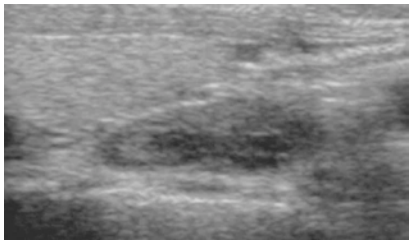
The thyroid in the Hashimoto's thyroiditis is always diffusely abnormal on ultrasound, with decreased inhomogeneous echogenicity.

Malignant thyroid lesions: Carcinoma of the thyroid is very rare. A solitary g***oiter*** is one of the most common forms of thyroid nodule may be malignant in 10% to 25% of cases. The risk of malignancy decreases with the presence of multiple nodules. A solitary thyroid nodule coupled with the presence of cervical adenopathy on the same side suggests malignancy.

Papillary thyroid cancer: is the most common and is the predominant cause of thyroid cancer in children. Approximately 20% of patients with papillary thyroid cancer have metastatic cervical adenopathy. **Sonographic appearance of malignancies:** it is usually hypoechoic relative to normal thyroid. **Note:** Thyroid carcinomas with the same echotexture as normal thyroid have been reported. Calcifications - They are common in all types of thyroid carcinoma. The specs of calcium are seldom peripheral as with adenomas. The interfaces of the lesion are often poorly defined and a halo is rarely present.

Parathyroid pathology:

Primary hyperparathyroidism: is the state of increased function of the parathyroid glands. Women have primary hyperparathyroidism two to three times more frequently than men; it is particularly common after menopause. Hypercalcemia, hypercalciuria, and low serum levels of phosphate characterize it. It occurs when increased amounts of PTH are produced by an adenoma, primary hyperplasia, or rarely, carcinoma, which is located in the parathyroid gland.

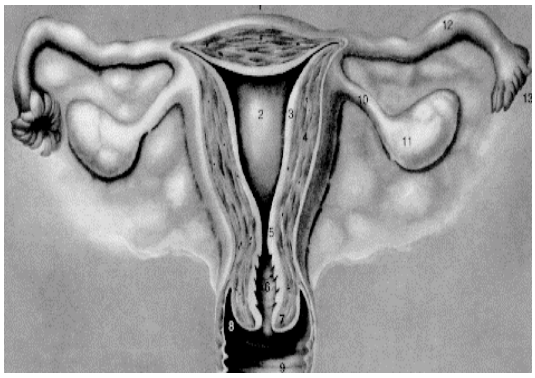


Adenoma: is the most common cause of primary hyperparathyroidism (70-80% of cases). A solitary adenoma may involve any one of four glands with equal frequency. **Sonographic appearance:** They are benign lesions and are usually .8 – 1.5 cm in length. The largest adenomas can be 5 cm or more in length. They appear hypoechoic and their shape is usually oval. The vast majority of adenomas are solid. They are encapsulated and have a discrete border

Carcinoma: It is difficult to differentiate carcinoma from adenoma with ultrasound due to their similar appearance. Metastases to regional nodes or distant organs, capsular invasion, or local reoccurrence must be present for cancer to diagnosed.

The Female Reproductive System

Sonography Of The Female Reproductive System



Uterus:

It is located in the mid region of the true pelvis. The organ lies superoposterior to the bladder and anterior to the sigmoid colon. The anterior and posterior walls are lined with peritoneum.

Vagina – extends from the uterus to the external genitalia. The vagina sits posterior to both the urinary bladder and urethra. It is anterior to the rectum.
Fallopian tubes - They extend laterally from the uterus to the ovaries. The tubes course within the peritoneal folds of the broad ligament. They are lateral to the uterus, anteromedial to the ovaries and posterior to the urinary bladder.
Ovaries - They lie within the peritoneal cavity, posterior to the broad ligaments. They are variable in their location. They can be located anywhere within the adnexal regions. The ovaries are most commonly located posterolateral to the uterus, however, they may be found superior or posterior to the uterus.
Vasculature – The ureters and internal iliac vessels course posterior to the ovaries. The iliopsoas muscles border the ovaries laterally. The external iliac vessels lie anterolateral to each ovary.

Gross anatomy: Muscles of the pelvis -

Iliopsoas (False pelvic muscle) - it is formed by the psoas muscle group and the iliacus muscle group at the iliac crest. They course anteriorly along the linea terminalis and travel over the pelvic brim to insert into the lesser trochanter.
Obturator internus (True pelvic muscle) - they originate along the arcuate line of the innominate bones and course parallel to the lateral walls of the true pelvis. They pass through the lesser sciatic notch and attach to the medial aspect of the greater trochanter. A tough membranous layer called the obturator fascia covers the internal surface.
Piriformis (True pelvic muscle) - they originate in the most posterior aspect of the true pelvis along the lower portion of the sacrum. These muscles travel anterolaterally and pass through the greater sciatic notch and attach to the superior portion of the greater trochanter.
Pelvic diaphragm – is a group of skeletal muscles lining the floor of the true pelvis supporting the pelvic organs. The pelvic diaphragm is composed of three paired muscles: the pubococcygeus, iliococcygeus, and coccygeus.

- *Pubococcygeus and iliococcygeus muscle groups* combine and form a hammock across the floor of the pelvis, which is called the levator ani muscles. They provide primary support to the pelvic viscera and aid in contraction of the vagina and the rectum.
- *Coccygeus muscles*– are the most posterior muscle pair of the pelvic diaphragm. They extend from the ischial spine to the sacrum and coccyx.

Vagina:

The vaginal canal is a blunt-ended cavity about 9 cm in length. The uterine cervix protrudes from the anterior vaginal wall into the upper portion of the vaginal canal. The space within the vaginal canal encircling the cervix forms the anterior, posterior, and lateral fornices of the vagina. It is highly elastic, permitting gross distention during parturition (Childbirth). In the relaxed state, the vaginal walls collapse together and the epithelial lining folds into transverse ridges, or rugae.

Uterus:

It is a pear shaped organ resting on the dome of the bladder in the midpelvis. The uterus is divided into four main regions: the fundus, corpus, isthmus, and cervix.

Fundus - It is the widest uppermost segment of the uterus. It is continuous with the body of the uterus. **Note:** This segment contains the cornua, which is where the fallopian tubes join the uterus.

Corpus – the body of the uterus.

Isthmus – is a short flexible region between the corpus and cervix.

Cervix – is the most inferior region of the uterus which extends into the upper portion of the vaginal canal. **Note:** This segment contains the internal and external os.

Uterine wall:

Composed of three layers: the endometrium, myometrium, and serosa.

1) Endometrium – is the inner wall of uterine tissue, which consists of epithelial cells and mucosal glands. **Note:** This is the area that builds up during the menstrual cycle.

2) Myometrium - it forms the largest part of the uterine wall. This middle layer is composed of smooth muscle fibers, a rich vascular supply, and supporting connective tissue. It is responsible for producing the radial contractions necessary to expel the fetus during childbirth.

3) Serosa – is a thin membranous layer surrounding the myometrium

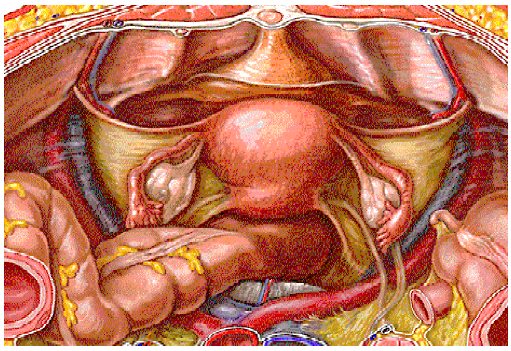
Cervical walls – are different than the rest of the uterus in that the smooth muscle fibers are interlaced with collagen fibers creating a more rigid framework.

Cul-de-sacs:

Anterior cul-de-sac– The thin space between the uterus and the bladder - a common site for fluid collection.

Posterior cul-de-sac (pouch of Douglas or rectouterine pouch) is the space between the posterior uterine wall and the rectum. Fluid collections within the peritoneal cavity drain within this space.

Ligaments and attachments:



Broad ligament-

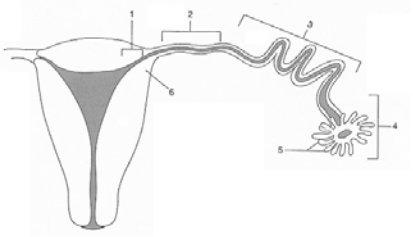
It is not a true ligament.
It houses the fallopian tubes.
It extends laterally from the uterus.

Round ligaments – maintain the forward bend of the uterine fundus.
Cardinal and uterosacral ligaments – provide more rigid support for the cervix.

Uterine positions:

Anteverted – the normal anatomical position for the uterus with an empty bladder. The uterus is tilted slightly forward, resting on the empty bladder.
Anteflexion – is defined by a marked anterior flexion of the uterus at the isthmus.
Retroflexion – is defined by a marked backward bend of the uterus at the isthmus, which extends towards the posterior cul-de-sac.
Retroversion – is another variation when the cervix is tilted posteriorly causing the fundus to extend posteriorly toward the rectum.

Fallopian tubes:



The Fallopian tubes are also called oviducts. They are coiled, muscular tubes extending from the cornua to the ovaries. The oviducts are approximately 10 cm in length and course within the parametrium of the broad ligaments. They conduct mature ova to the uterus through peristalsis of their smooth muscle walls. The inner mucosal lining is composed of ciliated epithelial cells and secretory cells. The cilia propel a gentle current of fluid, which aids in the transport of ova. They are divided into four segments: the interstitial segment, isthmus, ampulla, and infundibulum.

- *Interstitial* – is the first region of the tube which pierces the myometrium through the uterine cornua.
- *Isthmus* – is a short straight segment of the tube, which extends laterally from the interstitial segment.

- *Ampulla* – is the longest and most coiled portion of the tube where fertilization usually occurs.
- *Infundibulum* -
  - It is the funnel shaped portion of the tube closest to the ovary.
  - It does not directly communicate with the ovary.
  - It has *fimbria,* which are finger-like extensions that overlie the ovary. They direct the released ovum into the tube.

Ovaries:
They are almond shaped organs lying on the posterior surface of the broad ligaments. They are the only organs within the abdominopelvic cavity not lined with visceral peritoneum. The ovaries are composed of four layers of tissue: The stroma or body, which contains the peripheral cortex and central medulla, the germinal epithelium, and the tunica albuginea.

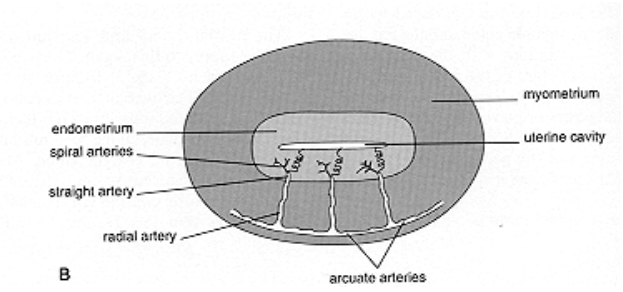
- Germinal epithelium – is a single layer of epithelial cells lining the outer surface of the ovary.
- Tunica albuginea – is a fibrous capsule composed of connective tissue found beneath the epithelial layer.
- Peripheral cortex – constitutes the bulk of the ovarian tissue and is the site of oogenesis (The production of female gametes).
- Medulla – contains the ovarian vasculature, lymphatics, and nerves.
- Ovarian hilum – is the doorway for ovarian vasculature as it enters and exits the parametrium of the broad ligament.

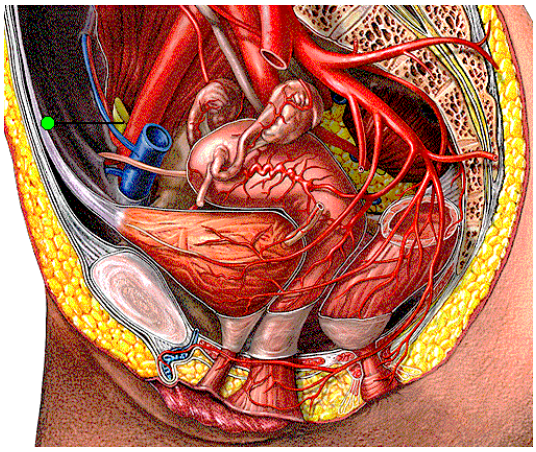
Note: The hilum is located on the superior aspect of the ovary.

Ovarian connective tissue is comprised of two ligaments, the infundibulopelvic ligament and ovarian ligament.

- Infundibulopelvic ligament – extends from the infundibulum and the lateral aspect of the ovary to the lateral pelvic wall.
- Ovarian ligament – supports the medial aspect of the ovary to the uterine cornua

Pelvic vasculature:





Pelvic vasculature is comprised of two main arteries: the uterine artery and ovarian artery. **Note:** The venous vasculature is identical to the arterial system. Uterine artery is a branch that extends from the internal iliac artery. *Arcuate arteries*– The uterine artery

also branches into the arcuate arteries which feed the uterus and ovaries. The arcuate arteries encircle the uterus and branch into the radial arteries. *Radial arteries* – The radial arteries penetrate the myometrium and give rise to the straight arteries. *Straight arteries* – supply the first layer of the endometrial tissue with smaller branches called spiral arteries. Ovarian artery and vein provide an alternative vascular supply to this organ. The left and right ovarian arteries branch off inferiorly from the aorta just below the level of the renal arteries. The right ovarian vein departs from the ovary superiorly and drains into the IVC just below the right renal vein. The left ovarian vein departs from the ovary and drains directly into the left renal vein.

Uterine Size:
Adult nulliparous uterus (Never having born a child) – is approximately 8 cm in length, 3 cm anteroposteriorly, and 5 cm in width. **Note:** The cervix is approximately 2 to 3 cm in length.
Child uterus measures 2.5 cm in length, 1cm in thickness, and 2 cm in width.
The cervix comprises a significantly greater proportion of the organ in the child than the adult. **Note:** During puberty the uterus enlarges and takes on its characteristic pear shape.
Multiparous uterus – is usually 1-2 cm larger than the nulliparous uterus.
Menopausal uterus – usually shrinks to the size similar to that of the child.
Endometrial thickness – varies with patient's age and phase of her menstrual cycle. The thickness is measured in the sagittal plane from its outer edge to outer edge anteroposteriorly. Postpubertal endometrium– ranges from 4 to 12 mm. Postmenopausal endometrium– should measure less than 10 mm.
Ovaries – Normal ovarian size varies during the life span. Reproductive years– The ovaries range from 2.5 to 5 cm in length, .6 to 2.2 cm in thickness, and 1.5 to 3 cm in width. Prepubertal and postmenopausal– The ovaries should not exceed 2 cm in length, 1 cm in thickness, and 2 cm in width. **Note:** If the postmenopausal patient is undergoing hormone replacement therapy the ovarian size can exceed these measurements.
Ovarian volume – is a valid way to evaluate ovarian size and is accepted and used in many practices. It is calculated as follows:
Volume =(length) x (AP thickness) x (width) x (.523)
Women 15-55 years = 6-13 cc
These parameters may be exceeded under normal conditions with the presence of a large follicle.

Prenatal development:

The reproductive organs develop with the urinary system from two urogenital folds in the early embryo. Each fold consists of a gonad and a mesonephros. The mesonephros is a precursor of the metanephros, the urogenital sinus, the Wolfian (mesonephric) ducts, and the Mullerian (paramesonephric) ducts. The metanephros and the urogenital sinus form the urinary system. The Wolfian and Mullerian ducts form the male and female genital tracts. The *bicornuate uterus* is the most common congenital malformation of the uterus. It results from incomplete fusion of the Mullerian ducts. **Note:** Since the urinary system and genital system form together you should always check the kidneys for other congenital malformations.

Physiology of the menstrual cycle: it is composed of a 28-day cycle during which a single ovum reaches maturity and is released into the genital tract. Hormones secreted by the anterior pituitary gland and by the ovary itself control changes in the ovary and endometrium. The menstrual cycle can be divided into two cycles: the ovarian cycle and endometrial cycle. Ovarian cycle is comprised of: the follicular phase, ovulation, and the luteal phase.

Follicular phase: This happens between days 1 to 14 of the ovulatory cycle. Follicle stimulating hormone (FSH) is produced by the anterior pituitary gland, which stimulates follicular development. The developing follicles release estrogen. 10 to 20 primordial follicles begin to mature. Out of those follicles only one matures into a graafian follicle. After the graafian follicle matures, it migrates to the surface of the ovary.

Ovulation: This happens around day 14 of the ovarian cycle. The graafian follicle expels the oocyte and releases 5 to 10 ml of follicular fluid into the peritoneal cavity where the fluid eventually settles into the posterior cul-de-sac. The fimbria from the oviduct draws the released egg into the infundibulum; the egg then courses towards the uterus.

Luteal phase: This phase occurs during days 15 to 28 of the ovarian cycle. The ruptured graafian follicle collapses, fills with blood, and is transformed into a temporary endocrine gland. The remaining follicular structure is now called the corpus luteum. Corpus luteum and hormone levels - secretes progesterone and estrogen, which promotes glandular secretions of the endometrium. **Note:** The glandular secretions are what build up the endometrium. Luteinizing hormone (LH)– is secreted by the anterior pituitary gland, which continues to stimulate the corpus luteum to secrete progesterone and estrogen. The corpus luteum continues to secrete estrogen and progesterone until the LH drops off. Progesterone– negatively inhibits the secretion of LH so that unless pregnancy occurs the corpus luteum withers away into a fibrous tissue mass and is called *corpus albicans*. When levels of estrogen and progesterone diminish, the thickened endometrium is shed through menstruation.

Pregnancy during the ovarian cycle:
Pregnancy interrupts the normal menstrual cycle. Human chorionic gonadotropin (HCG) is secreted by the developing placenta following the implantation of the fertilized ovum. HCG– like LH, maintains the corpus luteum so that it continues to secrete estrogen and progesterone throughout the first trimester. The placenta eventually takes over the entire endocrine function and the corpus luteum regresses forming the corpus albicans.

Endometrial cycle:

The days of the menstrual cycle are numbered according to the changes in the endometrial lining of the uterus.

Menses– Generally corresponds to Days 1 through 5, which is when the endometrium is shed.

Proliferative phase occurs during days 6 through 13 of the endometrial cycle. It is the second phase in the endometrial cycle occurring between menses and ovulation. The endometrium thickens in response to estrogen (from the developing follicles), preparing the uterine cavity to receive the fertilized egg.

Secretory phase - ovulation occurs on the 14th day of the cycle, which marks the beginning of the secretory phase. The production of estrogen and progesterone by the corpus luteum promotes continued proliferation of the endometrium. In the absence of fertilization, the production of LH, estrogen, and progesterone decreases and a new cycle begins on day one with menses. *Dual cycle timing* is the timing of menses and proliferative phase in the endometrial cycle corresponding with the follicular phase of the ovarian cycle (days 1 to 14). The secretory phase of the endometrial cycle corresponds to the **luteal phase** of the ovarian cycle (days 15-28).

Sonographic appearance: Transabdominal approach It requires a fully distended bladder which is used as an acoustic window. A full bladder also displaces small bowel from overlying the uterus and adnexal structures. This approach requires between a 3 and 5 MHz transducer. Most of the superficial anatomy is displayed at the apex (top) of the monitor. The posterior region of the pelvis is displayed at the bottom of the screen in the far field. ***Sagittal plane*** – The left and right sides of the display screen correspond to the cranial and caudal regions of the pelvis, respectively. ***Transverse plane*** – The left and right sides of the screen correspond to the right and left sides of the pelvis respectively. ***Transvaginal*** *approach* is performed with a high frequency transducer (5 to 7.5 MHz). The probe is inserted into the vagina approximately 4 inches. This approach requires an empty bladder to allow visualization of the uterus in the anteverted position. The inferior approach of transvaginal ultrasound allows for two scanning planes: coronal and sagittal. ***Sagittal view*** – The left and right sides of the screen correspond to the anterior and posterior regions of the pelvis, respectively. ***Coronal view*** – The left and right sides of the screen correspond to the right and left sides of the pelvis, respectively. Both the sagittal and coronal planes have the same appearance in relation to the top and bottom of the screen. The structures at the apex of the screen are the caudal regions of the pelvis. The structures at the bottom of the screen are the cranial regions of the true pelvis. To master the transvaginal scanning technique, the sonographer must understand how changes in the position of the probe affect image orientation. Comparison between the transvaginal and transabdominal approach. *Transvaginal* sonography is a newer technique. It displays superior resolution, but with limited visibility. *Transabdominal* sonography is usually easier to learn than transvaginal exams because it uses the same orientation as other transabdominal exams (gallbladder, kidneys, etc.). Poor resolution is

often observed due to the low frequency transducers needed to achieve the necessary imaging depth. A large field of view is the major advantage with this approach allowing for the sonographer to image the anatomy similar to cross sectional anatomy seen with computed tomography. Most departments use a combination of both approaches. However, some departments use only the transabdominal approach first, if poor visualization is obtained or suspected pathology is seen transabdominally, the radiologist will request a transvaginal study.

Urinary bladder: it appears as a black circular structure with a large amount of posterior enhancement. It is an important landmark in sonographic imaging of the pelvis. Under normal conditions, neither the ureters nor the urethra are visualized in pelvic sonography. Musculature– the most commonly visualized muscles of the pelvis are the iliopsoas, obturator internus, and pelvic diaphragm muscles.

Iliopsoas muscles: can be identified anteriorly in the transverse plane as ovoid structures lateral to the urinary bladder. They exhibit low-level echoes with a distinct central echogenic focus due to the femoral nerve sheath. They also can be identified in sagittal views along the lateral pelvic wall.

Obturator internus: are best demonstrated in the transverse scanning plane. These muscles appear as thin, linear low level echoes that are parallel to the lateral walls of the urinary bladder.

Pelvic diaphragm muscles: can be seen in transverse views of the cervix and vagina. The low level echoes of these muscles are seen in the far field on the transabdominal image. The muscle groups of the true pelvis are easier to visualize transabdominally and difficult to image transvaginally because of overlying bowel gas and reduced penetration.

Vagina: is seen posterior to the bladder neck when imaging the pelvis transabdominally. Sagittal plane – The muscle walls of the vagina appear as parallel layers of medium to low level echoes separated by a thin, echogenic stripe of vaginal mucosa. Transverse plane. The vagina has a flattened oval shape in the scanning plane. The muscles of the pelvic diaphragm can also be seen in this view posterior to the vagina.

Uterus: the uterine tissue exhibits homogeneous, medium to low level echoes. *Sagittal views* – The endometrium is seen as a longitudinal echogenic stripe lining the myometrium. *Transverse* – the width of the uterus can be fully evaluated in this scanning plane. Endometrial stripe thickness varies with the stage of the menstrual cycle. During menses and early proliferation – the endometrium appears thin and hyperechoic. Prior to ovulation– the endometrium thickens and takes on a multi-layered appearance. This sonographic appearance consists of a thin central echogenic line surrounded by a thicker hypoechoic layer that is separated from the myometrium by a thin, hyperechoic layer. This layered appearance continues to increase well into the secretory phase. Prior to menses–the endometrium appears thick, hyperechoic, and homogeneous.

Fallopian tubes: are not routinely visualized with ultrasound unless pathology is enhancing their size or appearance. Transvaginally, the sonographer can sometimes see the tubes extending laterally from the uterine cornua. The small dimensions of the tube make it difficult to distinguish between adjacent structures.

Ovaries: These organs are commonly identified lateral to the uterine fundus. They are slightly hypoechoic and more heterogeneous when compared to the uterine myometrium. During reproductive years, small anechoic follicles are often visualized within the ovaries. Ovarian size and shape vary considerably throughout the ovarian cycle. ***Pre ovulation*** – a mature graafian follicle is anechoic, with smooth walls, and measures approximately 18 to 22 mm in size. **Note:** The graafian follicle is sometimes referred as the dominant follicle. ***Post ovulation*** – immediately after ovulation the corpus luteum becomes irregular in shape and contains internal echoes due to hemorrhage.

Pelvic bowel:
Small bowel - loops of small bowel resting within the pelvic cavity appear heterogeneous and hyperechoic. They also demonstrate peristaltic activity. Gas in the small bowel can occasionally obscure visualization of the ovaries. ***Sigmoid colon and rectum*** do not demonstrate peristalsis. They appear echogenic with posterior shadowing due to bowel gas and fecal material. They can be identified posterior to the uterus and vagina.

Sonographic applications: Pelvic sonography is often used for the following situations: assessing the size and shape of the uterus and ovaries. Evaluating suspected uterine and ovarian masses in pediatric through geriatric populations using color and spectral doppler for assessing the vasculature of the ovaries. Managing infertility patients through frequent monitoring of follicular development detection and placement of an intrauterine contraceptive device (IUD).

Normal variants: retroverted, retroflexed, anteverted, and anteflexed uterus. Congenital malformations are due to incomplete fusion of the mullerian ducts. Post hysterectomy patient.

Pathology Of The Female Reproductive System

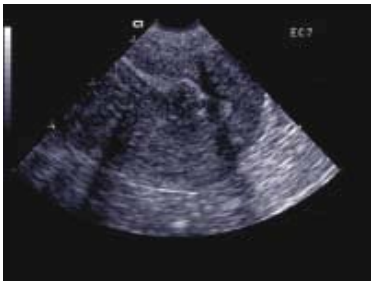
The Uterus, Cervix, & Vagina:

The Uterus

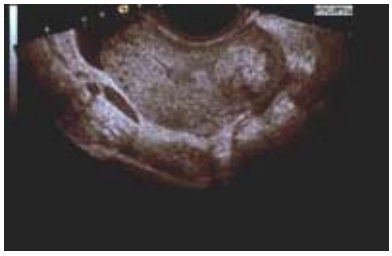
Leiomyomas

- They are commonly called fibroids.
- They are the most common gynecological tumors, occurring in approximately 25% of women of reproductive age. They consist of nodules of myometrial tissue and are usually multiple.
- Fibroids are the most common cause of uterine enlargement
- They are sensitive to estrogen stimulation and therefore increase in size during pregnancy.

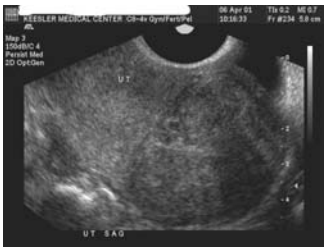
- They regress and calcify after menopause
- They are classified by their location within the myometrium (3 types)



  - **Submucosa**l – In this area the fibroid can deform the endometrial cavity and cause irregular, heavy menstrual bleeding



  - **Intramural** – In this location the fibroid deforms the myometrium.



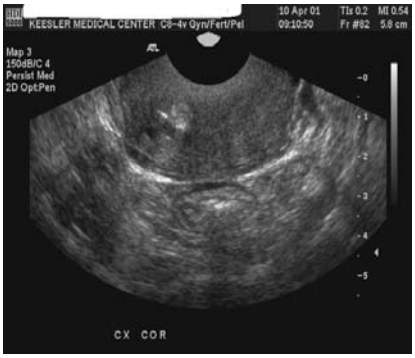
  - **Subserosal** – Distorts uterine margins. This type sometimes becomes pedunculated (stalk) and appears as an extrauterine mass.

Sonographic Evaluation:
When using endovaginal sonography, fibroids can be detected as small as 0.5cm and their relationship to the endometrial cavity can be defined precisely. Although ultrasound is a good diagnostic tool for evaluating fibroids, MRI is more sensitive in evaluating their location, size, and number. The earliest sonographic finding of fibroids is contour distortion along the interface between the uterus and bladder. Larger fibroids cause heterogeneous uterine enlargement. Discrete fibroids are usually hypoechoic, but can be hyperechoic if they contain dense fibrous tissue. Bright echoes occur with calcific deposits and produce typical acoustic shadowing.
Ultrasound measurements – The following uterine measurements should be included for fibroid evaluation:

- Cervix to fundus
- Widest transverse diameter of fundus
- Widest anteroposterior diameter
- Individual myomas are measured if they are discrete
- Thickness of the endometrial stripe should be documented.

Fibroid Cystic Degeneration:

This condition causes lucencies that are well visualized with transvaginal sonography. It often occurs with pregnancy and causes pain.



Uterine Calcifications:

Fibroids are the most common cause of uterine calcifications. They can appear as clumps of calcifications or as a rim of calcifications around a mass. **Arcuate artery calcification** is a less common cause. These calcifications are thought to occur as the consequence of cystic medial necrosis within these vessels and are usually seen around the periphery of the uterus. Cystic medial necrosis within these vessels, usually indicates underlying disease, such as diabetes mellitus, hypertension, and chronic renal failure.

Adenomyosis:

Is a benign invasive growth of endometrial tissue into the myometrium. Seen as an enlarged uterus without focal mass.

- Cause of heavy painful menses.
- Sonographic diagnosis difficult.
- Focal adenomyomas can occur

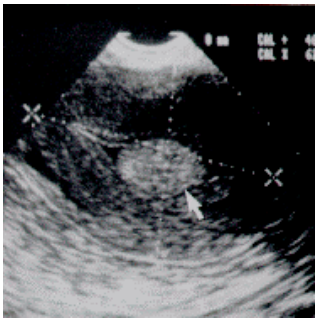
It is important to distinguish between fibroids and adenomyosis for infertility workup.

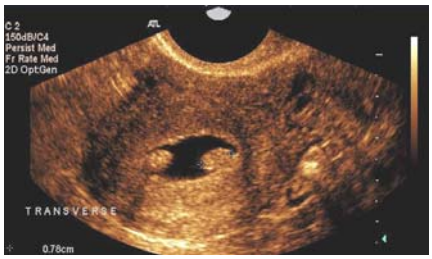
- Fibroids well circumscribed; adenomas ill defined.
- Fibroids can be removed; adenomyosis requires hysterectomy
- MRI helpful

Endometrial Abnormalities

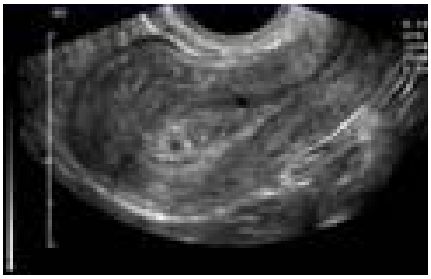
Endometrial hyperplasia:

Endometrial Hyperplasia is caused by unopposed estrogen. It appears as a thickening of the endometrium and may be diffuse or focal. In menstrual aged women, the endometrial thickness should be less than 16 mm. In the postmenopausal women, the endometrium is atrophic. In which case an asymptomatic woman with an endometrial thickness of less than 8 mm is normal. If she is symptomatic (bleeding), less than 4 mm is normal. In postmenopausal women on hormone replacement, the endometrial thickness varies depending on phase of cycle.

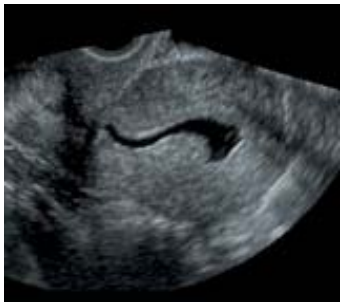




Endometrial Polyps:
They are usually asymptomatic but may cause uterine bleeding. They typically cause diffuse or focal endometrial thickening. They may also appear as an echogenic mass. (Visualizing a stalk with blood flow; confirms presence of polyp). Individual polyps are better visualized when surrounded by endometrial fluid.



Endometrial Carcinoma:
An early indicator of endometrial cancer is uterine bleeding. The earliest **sonographic** sign of endometrial carcinoma is a thickened endometrium. Demonstrating myometrial invasion is clear evidence for endometrial carcinoma. Advanced endometrial cancer presents with uterine enlargement, lobular contour, and mixed echogenicity of the myometrium. The level of invasion (superficial verses deep) can be detected endovaginally.



Endometrial Fluid Collections:
Fluid within the endometrial cavity is seen in both normal and pathologic conditions. Small amount of fluid is normal in menstrual phase of the menstrual cycle, and in early pregnancy. Other causes include infection, degenerating fibroids, and molar pregnancy. In older patients, fluid can be secondary to malignancy and could be caused by the following:

- Uterine, cervical, tubal, or ovarian carcinoma.
- Hyperplasia and polyps
- Prior irradiation for gynecological malignancies can result in pyometra or hematometra in women who have cervical stenosis.

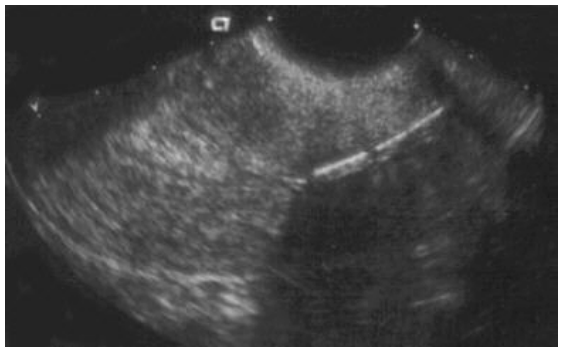
Benign conditions can also cause fluid collections such as:

- Congenital anomalies or cervical stenosis from prior instrumentation or childbirth.
- Abnormal development of the vagina or uterus, which results in a cystic uterine or vaginal collection of mucus in children.

Clinical symptoms include:

- Abdominal pain
- A globular abdominal mass
- Little or no vaginal bleeding
- The presence of fever usually indicates infection of the blood collection.

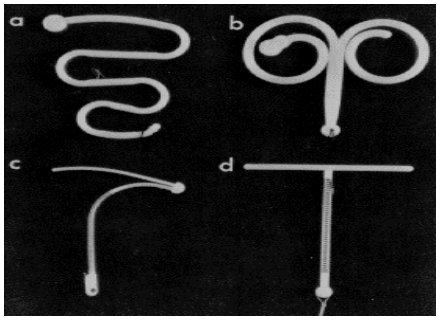
Lost IUD:



Clinical Indication

Proper placement of an IUD is verified by weekly digital palpation of the string in the cervix (performed by the patient). If the string is not felt in the cervix, the IUD may have been expelled or more likely, the string retracted into the cervix. A pregnancy test is then performed. If it is negative, the gynecologist explores the uterine cavity with a sterile hooked probe. If no IUD or string is found or if the pregnancy test is positive, an ultrasound is performed. The IUD should be located centrally within the endometrium. Patients with IUDs are also at increased risk for ectopic pregnancy and pelvic inflammatory disease.

Types of IUDs:



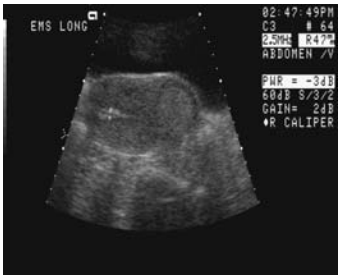
The ***Lippes Loop*** is serpentine and appears as a dotted line as the ultrasound beam transects the parallel segments in the longitudinal plane. The ***Copper 7*** is shaped like a 7, with a copper wire spiraled around the vertical shaft and appears on ultrasound as a "dot and a dash" longitudinally. The Tatum T and Progestasert are T-shaped and appear on ultrasound as a long echogenic line in the longitudinal plane. The notorious Dalkon Shield, which caused a number of serious complications and is rarely found in situ anymore, is a small, flat disk with hooks around the periphery. Occasionally a thick midcycle endometrium obscures the bright IUD echo when transabdominal ultrasound is used. If ultrasound does not detect the IUD, the next procedure is usually plain film radiography (if the patient is not pregnant).

IUD With Pregnancy:
When a pregnancy is present, ultrasound demonstrates both gestational sac and the location of the IUD. Approximately 50% of pregnancies abort on extraction of the IUD. With transvaginal scanning the location of the IUD can be detected relative to the sac, so it may be possible to predict which pregnancy will be disrupted.

Cervix:

About 3% of fibroids occur in the cervix. Other processes that extend into the cervix are polyps and uterine malignancies, and Nabothian Cysts.

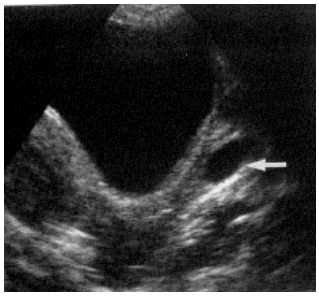
Nabothian cysts: They are caused by chronic cervicitis (infection) and are the most common mass within the cervix. They are frequently seen in middle-aged, postmenopausal women. They are usually anechoic, but may have debris. They usually measure less than 2 cm and may be multiple. Since the ovary frequently lies adjacent to the cervix, it is important not to confuse the ovary as nabothian cysts.



Cervical Carcinoma: Advanced cervical cancer is usually determined clinically, however, the sonographer may be called upon to evaluate the staging of the cancer. Typically cervical cancer appears hypoechoic with ill-defined margins. It can cause obstruction and hydrocolpos, as well as bleeding. Ultrasound is a superior modality for evaluating for local metastases, however, CT and MRI are the gold standard for evaluating lymphadenopathy.

Vagina:

Vaginal Cuff: It is defined as the area that is left after hysterectomy with a normal size of 2.1 cm or less. If the cuff is larger than 2.1 cm or contains a well-defined mass or areas of high echogenicity, it should be considered suspicious for malignancy.



Gartner's Duct Cyst: Located within or near vaginal wall and is usually palpable on physical exam.

Cul-De-Sac Fluid: Small amount of free fluid in cul-de-sac is normal throughout cycle. It usually occurs after rupture of a mature follicle. Complex fluid (with debris/septation) is abnormal.

- Premenopausal- results from hemorrhage, infection, or neoplasm.
- Postmenopausal- large amount of fluid is associated with various disease processes including malignant tumors.

Ovaries and Fallopian Tubes:

Fallopian Tubes And Pelvic Inflammatory Disease (PID)

The normal fallopian tube is generally not visualized unless fluid surrounds it. If outlined by fluid, it is a 1cm-thick tortuous structure. The normal lumen is not visualized, however, if fluid, pus, or products of conception fill the tube, detection is easier. If the lumen is outlined, a pathologic state is probable. Color-flow Doppler sonography is helpful in distinguishing an abnormally dilated fallopian tube from a dilated pelvic vein.

Pelvic Inflammatory Disease (PID):

PID is predominantly a complication of a sexually transmitted disease in which infection spreads from the cervix and endometrium to the fallopian tubes and finally to the ovaries and peritoneum. It is the most common cause of tubal obstruction, which can prevent normal fertilization, and implantation of the egg.

***Hydrosalpinx* -** Hydrosalpinx is caused by an obstructed tube filled with serous secretions. It can occur as a result of PID, endometriosis, or postoperative adhesions.

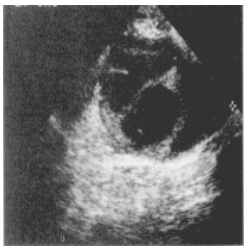
Pyosalpinx presents as echogenic fluid or fluid-filled levels within the tube.

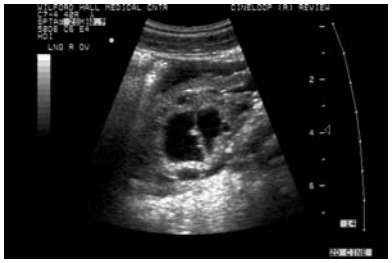
It is produced by infection in the tubes (internal debris may be noted). Acute salpingitis is evident as a thick-walled nodular hyperemic tube.

In addition to **hydrosalpinx** or **pyosalpinx, sonographic findings** of PID include:

- Fluid in the cul-de-sac
- Mild uterine enlargement
- Endometrial fluid or thickening

The unhealthy dilated tubes usually surround the ovaries and appear like two crescents of ring sausage encircling the posterior surface of the uterus and filling the cul-de-sac. The walls of the tubes are thickened and nodular. The ovaries may be difficult to delineate because of surrounding tissue, edema, and pus. Severe and chronic pyosalpinges often contain thick, echogenic mucoid pus, which does not transmit sound, as well as serous fluid or blood. Infection can obscure normal tissue planes, making anatomy unclear. Severe pain requires gentle use of ultrasound probes in acute PID, and in some cases a full bladder for a transabdominal study is intolerable.

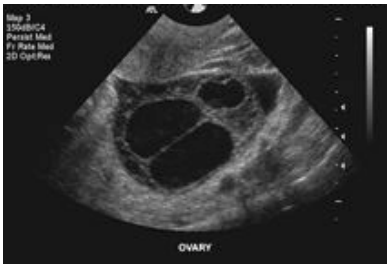




Tuboovarian Abscess (TOA):
It is defined as a loculation of pus, which is usually the next stage of progression from an untreated pyosalpinx. This may be unilateral or bilateral and appears as a complex mass in the posterior cul-de-sac. This process does not behave as a true abscess and usually responds well to antibiotic treatment without need for surgical drainage. Serial ultrasounds during treatment allow observation of resolution and can indicate which patients need prolonged intravenous antibiotics. **Sonographic appearance:**
A TOA appears as a complex hypoechoic adnexal mass with septations, irregular margins, and fluid-debris levels. It is ill defined when acute and a well defined, echogenic mass when chronic. The ovaries are often difficult to recognize as separate from the mass because of surrounding tissue, edema, and pus. Sonographic guidance is used to assist in percutaneous or transvaginal drainage and thus hasten recovery.

Pelvic Abscess:
It is usually a complex mass in the cul-de-sac that distorts pelvic anatomy. It can involve the ovary alone or the fallopian tube and ovary as a TOA.

Cystic Pelvic Masses



Functional Cysts:
These include follicular cysts, corpus luteum cysts, and hemorrhagic cysts. Functional cysts result from the normal function of the ovary. They are the most common cause of ovarian enlargement in young women. Most cysts measure less than **3 cm** in diameter and regress during the subsequent menstrual cycle (a follow-up examination in 6 weeks usually documents change). Hormonal therapy is sometimes administered to suppress a cyst.

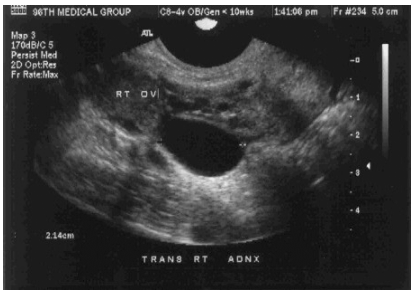
Follicular cyst:

- occurs when a mature follicle fails to ovulate.
- are usually unilateral and measure less than 2.5 cm in size.
- can be as large as 20 cm in diameter and they usually regress spontaneously.

Corpus luteum cysts:

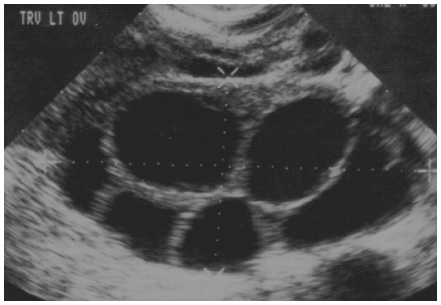
- result from failure of absorption or excess bleeding into the corpus luteum.
- are common during the first trimester of pregnancy, when maximum size is reached by 10 weeks, and resolution occurs by 16 weeks.

- cysts usually are 2-10 cm in diameter.
- are prone to hemorrhage and rupture.
- presenting clinical sign is adnexal pain.
- usually appear as a complex mass with a central blood clot and echogenic septations.
- difficult to distinguish from ectopic pregnancy and endometriosis.



Paraovarian cysts:

- arise from the broad ligament and usually are of mesothelial or paramesonephric origin.
- account for approximately 10% of adnexal masses.
- are difficult to distinguish from ovarian cysts.
- can become large but rarely are symptomatic.
- size does not change with the hormone cycle.



Theca lutein cysts:

- appear as large, bilateral, multiloculated cystic masses.
- are associated with high levels of human chorionic gonadotropin (HCG).
- are seen most frequently in association with gestational trophoblastic disease (30%).
- sometimes occur in patients being treated with infertility drugs (particularly Pergonal), multiple gestations, and/or molar pregnancies.
  (Similar cysts occur in normal pregnancies, especially multiple gestations.)

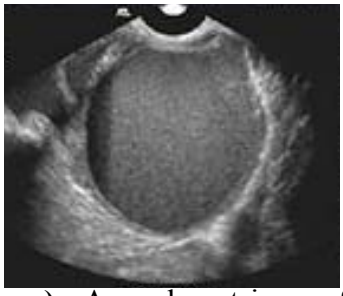
Polycystic ovaries:

- defined as an endocrinologic disorder associated with chronic anovulation.
- associated with Stein-Leventhal syndrome (infertility, oligomenorrhea, and hirsutism).
- pathologically, the ovaries contain an increased number of follicles.

- the number of small follicles is increased bilaterally (usually more than 5 in each ovary.)
- Endovaginal sonography is more sensitive for detecting these small follicles than transabdominal scanning.

Complex Pelvic Masses

Endometriosis:
It is a common condition in which functioning endometrial tissue is present outside the uterus. The ectopic tissue is usually found on the ovaries, the external surface of the uterus, and scattered over the peritoneum. The endometrial tissue cyclically bleeds and proliferates. It exists in two forms, ***diffuse*** and ***localized.*** **Diffuse form**–leads to disorganization of the pelvic anatomy with an appearance similar to PID or chronic ectopic pregnancy.



Localized form (endometrioma): An endometrioma often appears as a simple cyst with transabdominal ultrasound. With transvaginal ultrasound, internal echoes are usually seen. Its most common presentation is of a "chocolate cyst" with low-intensity echoes and acoustic enhancement. Other appearances include an enlarged polycystic ovary with a thick wall and internal septations or a cyst with fluid-debris levels.

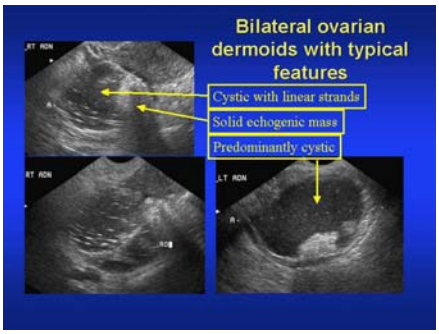
Ovarian Neoplasm Morphology:
Mixed cystic and solid masses are the most frequent presentation of the common epithelial tumors of the ovary. Ultrasound can describe the tumor morphology but cannot (with the exception of dermoid cysts) distinguish benign from malignant tumors. Simple cysts are probably benign, whereas cysts with thick septations and solid elements are frequently malignant. Ascites, extension to adjacent organs, peritoneal implants, lymphadenopathy, and hepatic metastases support the diagnosis of malignant disease.

Ovarian Carcinoma:
Ovarian carcinoma is the leading cause of death from gynecologic malignancy in the U.S. About 80% of cases involve women over 50 years of age. The risk of cancer increases with age. At presentation of symptoms, most cancers are at an advanced stage. For these reasons, transvaginal ultrasonography, has been advocated as the best method for evaluating postmenopausal ovarian masses or abnormally enlarged ovaries. Approximately 70% of ovarian malignancies are common epithelial tumors, the majority of which are cysts.

Epithelial Tumors:
70% are benign and 30% malignant. The benign or low-malignant-potential form is termed adenoma (cystadenoma) and the malignant form is termed adenocarcinoma (cystadenocarcinoma). The prefix cyst is added if the lesion is cystic, and fibroma is added if the tumor is more than 50% fibrous. Epithelial tumors can be very large. They often fill the pelvis and extend into the abdomen. The two most common types are ***serous*** and ***mucinous.***

Mucinous tumors:
They are usually thin-walled multilocular cysts. They often contain internal echoes (debris) with compartments differing in echogenicity. Malignant cysts tend to have thick, irregular walls and septations. If they rupture, this causes loculated ascites with mass effect.

Serous tumors:
They are usually unilocular. Serous tumors tend to be anechoic with septations. Malignant tumors have irregular textures with papillary projections. Solid elements or bilateral tumors also suggest malignancy.



Dermoids:
Dermoids are the most common ovarian neoplasm. They comprise 20% of ovarian tumors. Up to 20% are bilateral and about 80% occur in women of childbearing age. Malignant degeneration into squamous cell carcinoma frequently occurs in teratomas, usually in older women. Immature teratomas occur in people 10 to 20 years of age. These are rapidly growing malignant solid tumors with many tiny cysts.

Dermoids have a spectrum of sonographic appearances, depending on which elements (ectoderm, mesoderm, or endoderm) are present. A dermoid can have the following **sonographic characteristics:**

- Completely cystic mass
- Cystic mass with an echogenic mural nodule High-amplitude echoes with shadowing (teeth or bone).

- Complex mass with internal septations.

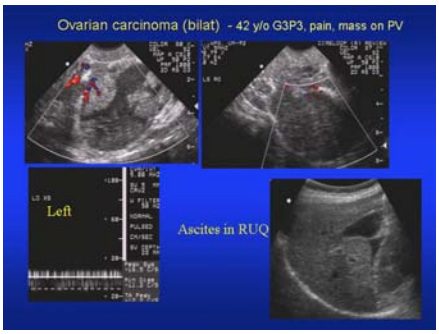
Teeth, bones, and fat can be seen on plain films. Echogenic dermoids often are confused with bowel. If a palpable pelvic mass is present that is not identified on ultrasonography, an echogenic dermoid must be considered. Indentation on the bladder wall will be a clue that a mass is present.

Solid Tumors:

Solid adnexal masses are often difficult to diagnose because normal ovarian size varies widely. Typically, an ovary is considered abnormal when its volume is twice that of the opposite side. When a solid mass is found, care should be taken to identify a connection with the uterus to differentiate an ovarian lesion from a pedunculated fibroid. An entirely solid ovarian mass in a woman less than 30 years of age is usually a dysgerminoma. An ovarian fibroma with ascites and pleural effusion is associated with **Meigs' Syndrome** (These findings can also occur with other ovarian neoplasms).

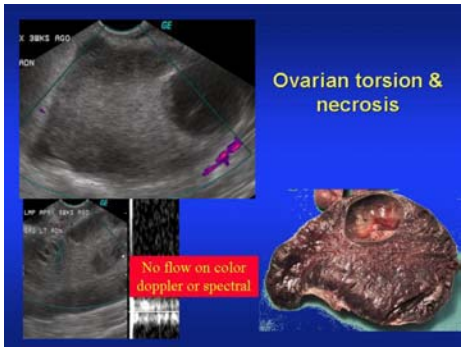
Germ cell tumors:

This tumor group includes teratoma, dysgerminoma, embryonal cell carcinoma, choriocarcinoma, and endodermal sinus tumor. With the exception of teratomas, all are rare. They often occur as mixed tumors with elements of two or three varieties of germ cell tumors. They are associated with elevated AFP and HCG levels.



Metastatic disease:

The ovary is a common site of metastases from bowel (Krukenberg tumor), breast, and endometrium, as well as from melanoma and lymphoma. Metastatic disease to the ovaries frequently is bilateral and is often associated with ascites. Metastases are usually completely solid or solid with a "moth-eaten" cystic pattern.



Ovarian torsion:

It is caused by partial or complete rotation of the ovarian pedicle on its axis. It usually occurs in childhood and adolescence and is common in association with adnexal masses.

It produces an enlarged edematous ovary, usually greater than 4 cm in diameter. It most commonly presents as a solid adnexal mass and free fluid is often present in the pelvis. Doppler examination usually reveals absent blood flow to the torsed ovary; however, recent studies reveal normal blood flow to torsed ovaries in some cases. This is thought to be the result of the dual blood supply of the ovary or because of venous thrombosis.

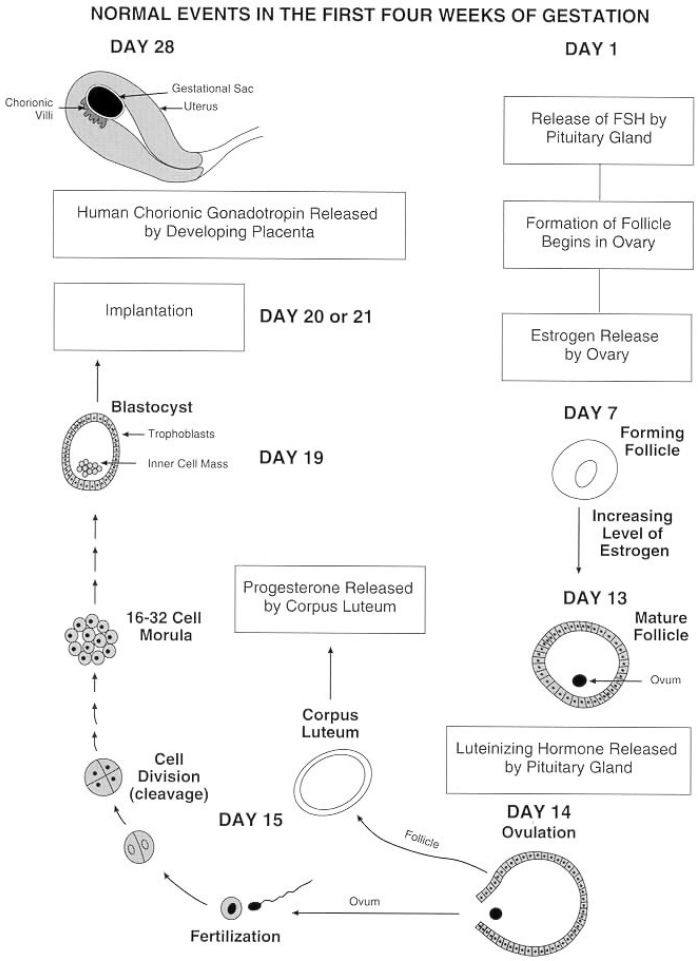
First Trimester Sonography

First Trimester Sonography

Fertilization And Early Development:

1st Trimester: week 1 to week 12
2nd Trimester: week 12 to week 28
3rd Trimester: week 28 to week 40
(over 42 weeks = post term or post date gestation)

Embryonic age = day 1 begins on day 15 of menstrual cycle
Menstrual age = day 1 begins on day 1 of menstrual cycle
Gestational age = day 1 begins on day 1 of menstrual cycle



Day 14– ovulation occurs

Day 15–19

- Fertilization occurs in the distal third of the tube on day 15.
- The ovum is now referred as the *zygote.*
- The zygote will start to divide and form a cluster of 16 to 32 cells called the *morula*.

Day 20

- The morula continues to grow and forms the blastocyst by day 20.

- The blastocyst is a fluid filled cyst lined with trophoblastic cells and an inner cell mass.

Days 20-23– Implantation into the uterine endometrium usually occurs.

- Endometrial cells next to the blastocyst become modified to supply nourishment to the early embryo for development.
- This change in the endometrium is called the *decidual reaction.*
- A primitive uteroplacental circulation is formed via the *chorionic villi.*

NOTE: Chorionic villi are finger-like projections of the outermost embryonic tissues extending into the diciduate uterine tissues.

Week 4

- The inner cell mass changes dramatically
- It forms an embryonic disc, an embryonic cavity, and a primary yolk sac.
- The primary yolk sac regresses by the end of week four and a secondary yolk sac is formed between the amnion (the innermost membrane of the embryo) and the chorion (the outermost tissues of the embryo).

Week 5

- A very small gestational sac exists.
- When the embryo implants in the uterus, the chorion starts to produce human chorionic gonadotropin (HCG) which stimulates the corpus luteum to grow and continue to produce progesterone.

Note: The corpus luteum will continue to grow to about 4 cm in diameter and will then regress, disappearing by twelve weeks.

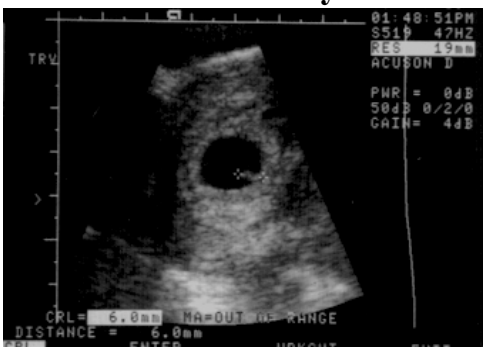
- The gestational sac is made up of numerous layers of tissue:
    - *Decidua*– is the changed lining of the uterus during pregnancy. It is composed of the following tissue layers:
        - Decidua basalis–is a thick decidua existing at the implantation site.
        - Decidua vera (decidua parietalis)– is the decidua along the remainder of the endometrial cavity, beside the implantation site.
        - Decidua capsularis– is the thin decidua overlying the portion of the gestational sac facing the endometrial cavity.
    - *Chorion*
        - It is the embryonic tissue lining the exterior of the gestational sac.
        - Its purpose is to invade the decidua and establish nutrition for the embryo.
        - Chorion frondosum– is the portion of the chorion located at the implantation site.

          Note: It contains the chorionic villi, which actively invade the decidua of the uterus.
        - Chorion laeve– is the thin chorionic covering of the gestational sac facing the endometrial cavity.
    - *Amnion*
        - Is the inside sac which makes contact with the fluid surrounding the embryo.

- The chorion and the amnion eventually fuse together by the 16th week of pregnancy.

- *Amniotic fluid* – It is the fluid that surrounds the embryo. It has five functions:
  - It permits symmetrical growth of embryo and fetus.
  - It prevents adhesions from forming in the fetal membranes.
  - It cushions the embryo; it acts as a "shock absorber."
  - It helps maintain the temperature of the embryo.
  - It allows for fetal movement which helps develop muscle tone.

Sonographic Appearance Of The Early Gestation:



5-6 weeks:
The 5 week gestational sac should present with a *double sac sign*. **Note:** This sign is what differentiates a real g-sac from a pseudosac. Double sac sign– is two echogenic concentric rings separated by a hypoechoic zone. The inner ring is the decidua capsularis and the chorion laeve and the outer ring is the decidua vera. The secondary yolk sac should be visible at 5 to 6 weeks. **Note:** The yolk sac is about 5-6 mm at this stage.
6 weeks: The embryo is visible by 6 weeks, earlier if using the endovaginal approach.
7 to 9 weeks: The head and rump of the embryo will become discernable depending on the equipment used, the patient body habitus, and the sonographer's skill.

Embryology Of Individual Organ Systems And Their Sonographic Appearance:

Most of the organs and systems have been developed as early as 10 menstrual weeks of age. At 10 weeks the embryo is considered a fetus, which now has a central nervous system, cardiovascular system, respiratory system, and abdominal organs.

Central Nervous System

Starts with the most primitive component, the *neuroplate*, which develops at 4 to 5 menstrual weeks. The neuroplate will then form the neurocrest and the neurotube. The neurotube will eventually form the brain and spinal cord. By the sixth menstrual week, the primitive embryonic brain consists of three segments: the forebrain (proencephalon), the midbrain (mesencephalon), and the hindbrain (rhombencephalon). The anterior portion of the neurotube forms the following:

- Forebrain – will eventually become the cerebrum, thalamus, and lateral ventricles.

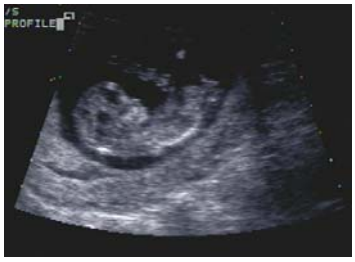
- Midbrain – will become the midbrain in the adult and it will also form the aqueduct of Sylvius.
- Hindbrain - will develop into the pons, medulla, cerebellum, and the fourth ventricle of the adult.

The posterior portion of the neurotube will develop into the fetal spine and spinal cord.

- The anterior-posterior ends of the tube are closed by the sixth week of development.
- Mineralization of the fetal spine does not begin until 8 weeks of development.

Sonographic Of Appearance Of The Early Central Nervous System

10 weeks: The brain appears as an anechoic fluid-filled mass.



12 weeks

- Two hyperechoic structures can be identified within the fetal skull
- **Note:** These two structures are called the *choroid plexus,* which produce the cerebrospinal fluid in the embryo.
- The developing cerebral cortex is present but is not normally seen with ultrasound prior to 12 weeks.
- Measurements – Two measurements of the skull are taken at 12 weeks and greater, the biparietal diameter (BPD) and the head circumference (HC)

Embryonic heart:

It begins with two tubes which eventually fuse along their midlines to form a very primitive tubular heart. All four chambers are complete by 12 weeks of development.

Sonographic appearance of the heart:

- Pulsations in the tubular heart may be seen as early as 5.2 weeks if the transvaginal approach is employed.
  Note: With the transabdominal approach, a beating heart is usually seen by 6.5 weeks.
- Cardiac activity should be noted by 7 weeks in most pregnancies if the embryo is viable.
- The structural components of the heart are not seen with ultrasound until late in the second trimester.

Embryology Of The Fetal Lungs:

They are not visualized until midway into the second trimester.

Embryology Of The Abdominal Organs:
The embryo forms the alimentary canal when the primary yolk sac regresses which eventually forms the foregut, midgut, and the hindgut.

- Foregut – forms into the pharynx, esophagus, stomach, proximal duodenum, liver, and pancreas.
- Midgut – forms the small intestine and a portion of the colon.
- Hindgut – forms the distal colon, rectum, and portions of the bladder.

Sonographic appearance of the abdomen:
During the 8th to 11th week of pregnancy the small bowel usually herniates out of the embryo at the base of the umbilical cord. This is a normal event but the bowel should retract into the abdomen by 12 weeks of development.

Note: This is very important to remember because this is why omphalocele occurs. At 12 weeks the bowel will return into the abdomen.

Note: The fetal stomach is not seen until the early second trimester.

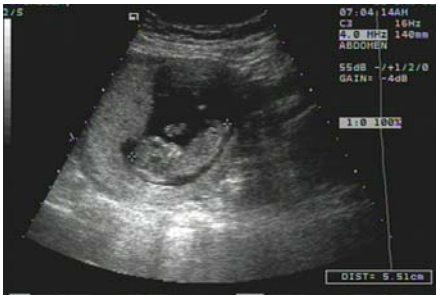
Embryology Of The Fetal Genitourinary System:
Functional kidney tissue begins to develop around 10 menstrual weeks. The production of fetal urine does not occur until early in the second trimester. The fetal genitourinary system is not visualized sonographically until the second trimester.

Embryology Of The Fetal Skeleton:
The fetal skeleton does not begin to mineralize until the 8th gestational week. The fetal skull and femur are adequately mineralized by 11.5 to 12 weeks.

Sonographic appearance of the skeleton:

- Mineralization of fetal bones allows for their visualization by ultrasound.
- Weeks 8 to 9 – Fetal buds can be imaged.
- Weeks 10 to 12 – Fetal limb movement can be detected.
- Week 11 to 12 – The fetal skull and femur can be visualized.

Sonographic Measurements:



Crown-rump length - It is the measurement from the top of the head to the bottom of the rump. If done correctly, it is accurate to within four days. It is the most accurate measurement for determining gestational age in the first trimester.

Gestational sac diameter - Measuring the three inner dimensions of the sac and dividing it by three to get the mean sac diameter. When the gestational sac exceeds 10 mm (endovaginally) in mean internal diameter, a yolk sac should be seen.

TA=15mm EV=10mm

The yolk sac should not exceed 5.6 mm (endovaginally) in diameter. Anything larger than 6 mm has been associated with a poor pregnancy outcome.
When the mean sac diameter reaches 18 mm, an embryo should be seen.

TA=25mm EV=18mm

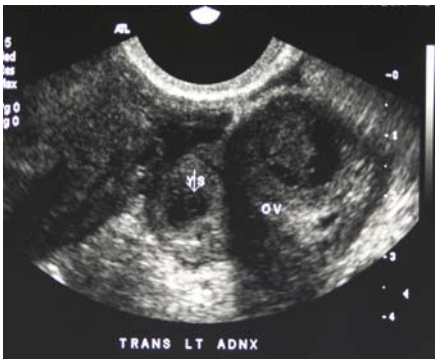
The mean sac diameter has an accuracy of only + or – 2 to 3 weeks in 90% of cases.

Sonographic Applications:

There are many possible medical indications for a women to receive a first trimester sonogram. The ten most common are as follows:

- Vaginal bleeding – to determine gestational viability or to rule out an ectopic pregnancy
- Pain – to rule out a mass, an abruption, or an ectopic pregnancy
- Large for dates – to rule out a mass, multiple gestation, fetal anomaly, or incorrect menstrual history
- Small for dates – to rule out fetal death, a fetal anomaly, incorrect menstrual history, or ectopic pregnancy
- Unknown menstrual date – to determine correct gestational age for follow-up prenatal care.
- Substance abuse – to rule out fetal anomalies and to determine the growth rate of the fetus
- Intrauterine contraceptive device (IUD) – The presence of an IUD can complicate a pregnancy.
- Trauma – to determine fetal well-being
- History of multiple gestations or women undergoing fertility therapy
- History of miscarriage

First Trimester Abnormalities:



Ectopic Pregnancy:

Ectopic pregnancy is one of the most crucial diagnoses made in ultrasound. It is related to approximately 15% of maternal deaths. The prevalence of ectopic pregnancy in a clinically suspected group varies according to the patient population and their inherent risk factors (approximately 10% to 40%). In approximately 95% of cases, ectopic pregnancy occurs within the fallopian tubes. Other sites of occurrence are the ovary, broad ligament, peritoneum, and cervix.

Clinical Findings Of Ectopic Pregnancy:

- Pelvic pain has been reported in 97% of patients.
- Vaginal bleeding (75% of patients).
- A palpable adnexal mass (50% of patients).
- Positive pregnancy test (100% of patients. Duh!!)

Correlating Clinical Findings With Beta HCG Levels

Correlating clinical tests with sonographic findings in ectopic pregnancy is imperative for diagnosis. Specific tests for human chorionic gonadotropin (HCG) allow the sonographer/sonologist to have expectations of sonographic findings, or lack thereof.

Laboratory Standards

The beta-HCG is quantified from maternal blood by **two** standards, the **First International Reference Preparation (1st IRP)** or the **Second International Standard (2IS).** It is crucial that the sonographer understand which HCG standard that their particular institution is using. Quantification of HCG is directly correlated with gestational age throughout the first trimester. The First IRP has approximately double the HCG quantities of the 2IS.

Beta HCG Discriminatory Level For Detecting Pregnancy

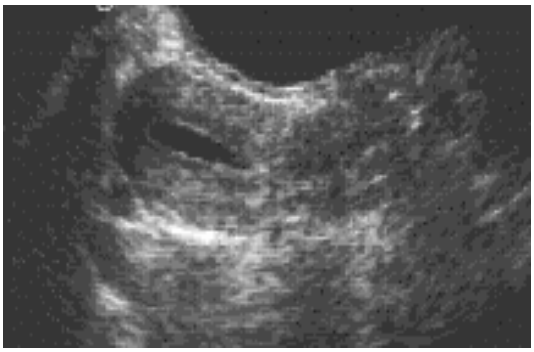
The sonographer should have a good understanding of the discriminatory level of HCG and sonographic findings. The discriminatory level of HCG in pregnancy should be thought of as a minimum level of HCG in normal IUP or ectopic pregnancy. Endovaginally, the HCG discriminatory level in detecting an IUP has been shown to be 800 to 1000 IU/L based on the 2IS and 1000 to 2000 IU/L based on first IRP. If the beta-HCG discriminatory levels are met or surpassed and no intrauterine gestational sac is seen, an ectopic pregnancy should be suspected. Caution should be taken however, if beta HCG levels are below discriminatory levels. Ectopic pregnancy may or may not exist, given that ectopic gestations do not produce HCG at normal levels. Since ectopic gestations are not viable, they may not reflect typical correlation between gestational age and HCG levels.

Serial beta-HCG levels - In nonemergent cases, serial beta-HCG levels are preferred because trending of these levels would demonstrate a continuing pregnancy, if HCGs rise normally or slowly or plateau. Falling HCG levels may indicate missed or incomplete abortion.

Sonographic Findings With Ectopic Pregnancy:

Normal IUP Identification:

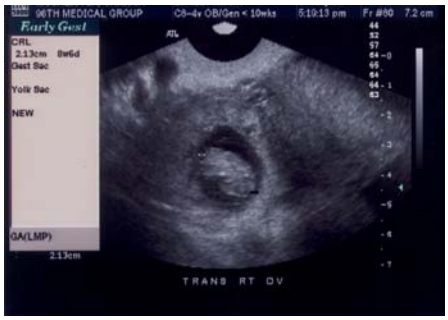
The most important finding when scanning for ectopic pregnancy is identification of a normal intrauterine gestation. Again, the expectation of visualizing a normal intrauterine gestation is directly correlated to beta-HCG levels. An intrauterine gestational sac that includes embryonic heart motion firmly makes the diagnosis of intrauterine pregnancy. Earlier gestations (5 to 6 weeks) may normally not demonstrate these findings. As many as 20% of patients with ectopic pregnancy have a intrauterine saclike structure known as the pseudogestational sac.



Pseudogestational sac: Although difficult, differentiating between a normal early gestation and a pseudogestational sac is often possible. The following guidelines may be helpful:

- Pseudogestational sacs do not contain either a living embryo or yolk sac.
- In patients with ectopic pregnancies, the deciduas may slough, resulting in a fluid collection within the endometrial canal referred to as a *decidual cast* or *pseudogestational sac*.
- Unlike normal gestational sacs, homogeneous level echoes are commonly observed in pseudogestational sacs.

Adnexal Gestational Sac: The adnexa should always be sonographically examined when evaluating for ectopic pregnancy. The identification of an extrauterine sac within the adnexa is one of the most frequent findings of ectopic pregnancy. It has been reported that a tubal ring can be found in 49% of patients with ectopic pregnancy and in 68% of those with unruptured tubal pregnancies using EVS (A tubal ring is an echogenic adnexal ring separate from the ovary created by the trophoblast of the ectopic pregnancy surrounding the gestational sac). The extrauterine gestational sac has sonographic appearances and characteristics similar to the intrauterine gestational sac.



Adnexal Mass With Ectopic Pregnancy

Mass identification: The presence of an adnexal mass in patients with a positive β-HCG who have no sonographic evidence of an intrauterine pregnancy, however, has a positive predictive value of 70% to 75% for ectopic pregnancy. Complex adnexal masses, aside from extrauterine gestational sacs, often represent hematoma within the peritoneal cavity. This is usually contained within the fallopian tube or broad ligament. In early gestational ectopic pregnancy, hematoma may be the only sonographic sign of ectopic pregnancy.

Fluid in cul-de-sac:

80% of patients with ectopic pregnancy demonstrate at least 25 ml of blood within the peritoneum. This is caused by blood escaping from the distal tube (fimbria). Free intraperitoneal fluid detected sonographically is also a common finding in ectopic.

Adnexal mass and free pelvic fluid:
In patients with suspected ectopic pregnancy, the combination of an adnexal mass and echogenic free fluid is associated with a 97% positive predictive value for ectopic pregnancy.

False negative sonograms:
A sonographer should realize that not all ectopic pregnancies will be identified by sonography. Some studies reveal that 25% of adnexal masses can be missed due to overlying bowel or an atypical location of the mass. If there is a positive pregnancy test and no adnexal mass or free fluid is identified, ectopic pregnancy cannot be excluded.

Heterotopic Pregnancy (Simultaneous Intrauterine And Extrauterine Pregnancy):
Simultaneous intrauterine and extrauterine pregnancy is very rare (1 in every 7000) (greater in high-risk groups). Ovulation induction and in vitro fertilization with embryo transfer lead to higher risk of heterotopic pregnancies. Also leads to an overall increase in ectopic pregnancies, including bilateral ectopics.

Endovaginal Color Flow Doppler (EVCFD):
EVCFD diagnosis of ectopic pregnancy is based on the identification of adnexal peritrophoblastic flow defined as high-velocity, low-resistance flow separate from the ovary. EVCFD increases the diagnostic sensitivity for diagnosis of ectopic pregnancy compared with EVS alone (EVCFD should only be utilized as confirmation of ectopic pregnancy, and not base the diagnosis of ectopic pregnancy solely on presence of low-resistance flow). Although the absence of low-resistance flow cannot exclude ectopic pregnancy, it may be related to early or dead ectopic pregnancies.

Interstitial Pregnancy (Cornual Pregnancy):
It is potentially the most life threatening of all ectopic gestations. The location of this ectopic pregnancy lies in the segment of the fallopian tube that enters the uterus. This site involves the parauterine and myometrial vasculature, which could create life-threatening hemorrhage if rupture occurs. It occurs in approximately 2% of all ectopic pregnancies. Sonographic identification of an interstitial ectopic pregnancy is difficult. If the gestational sac encroaches to within **5 mm** of the uterine serosa, an interstitial ectopic pregnancy should be suspected.

Cervical Pregnancy:
A Sonographic demonstration of a gestational sac within the cervix suggests a cervical pregnancy (A spontaneous abortion may have a similar appearance). It has a reported incidence of 1 in 16,000 pregnancies.

Ovarian Pregnancy:
This condition is also very rare, accounting for less than 3% of all ectopic pregnancies. Its sonographic diagnosis may be difficult, since reported cases have demonstrated complex adnexal masses that involve or contain ovary. **Note:** Distinguishing it from a hemorrhagic ovarian cyst or from other ovarian processes may also be difficult.

Complete abortion:

Sonographic characteristics: are an empty uterus with no adnexal masses or free fluid and positive HCG levels. Serial HCG levels demonstrate rapid decline. Caution should be taken when a positive pregnancy test and an empty uterus are seen. **Note:** The possibility that an early normal intrauterine pregnancy between 3 and 5 weeks may be present. Consequently, serial HCG levels should always be obtained.

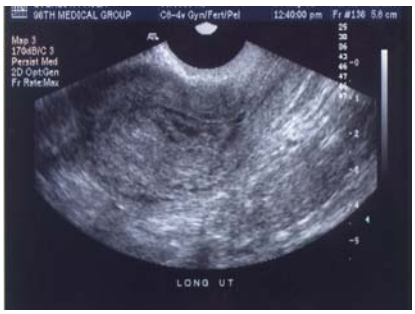
Incomplete abortion:

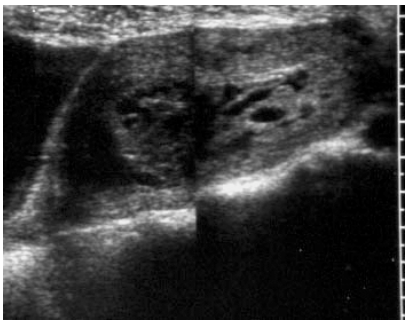
It may show several sonographic findings, ranging from an intact gestational sac with a nonliving embryo to a collapsed gestational sac with gross misshaping. Often women who are clinically undergoing abortion require follow-up sonography to check for *retained products of conception*.

Retained products of conception: they may be subtle; a thickened endometrium may be the only sonographic evidence of such diagnosis. Some products may be very obvious, such as embryonic parts, which may or may not cause acoustic shadowing.

Blighted ovum or anembryonic pregnancy:

It is defined as a gestational sac in which the embryo fails to develop. **Sonographic appearance:** It typically appears as a large empty gestational sac that does not demonstrate a yolk sac, amnion, or embryo. The sac size, typically, is clearly abnormally large (greater than 18 mm mean sac diameter). No intragestational sac anatomy is seen.



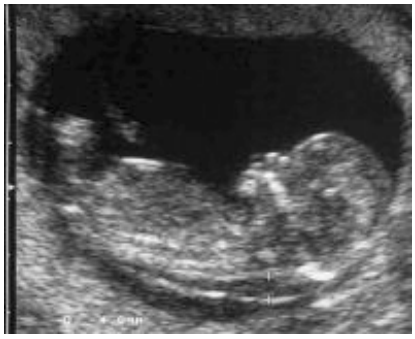


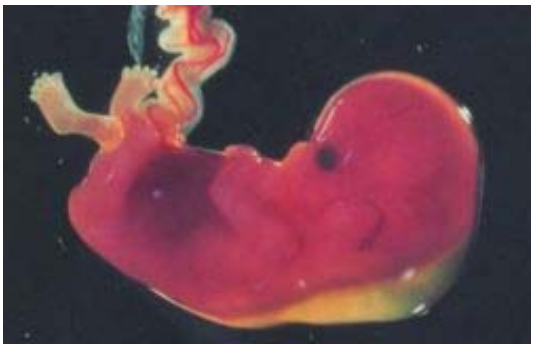
Gestational trophoblastic disease:

It is a proliferative disease of the trophoblast after a pregnancy. It represents a spectrum of disease from a relatively benign form (hydatidiform mole) to a more malignant form (invasive mole) or choriocarcinoma. In the US, this disease affects approximately one out of every 1500 to 2000 pregnancies. **Note:** In some Asian countries, it affects more than 1 in 100 pregnancies. **Clinical findings:** The clinical hallmark of gestational trophoblastic disease is vaginal bleeding in the first or early second trimester. The beta-HCG serum levels are dramatically elevated, often greater than 100,000 IU/ML. The patient may also experience symptoms of hyperemesis gravidarum or preeclampsia. Reports show associations with women over age 40 and molar pregnancy. Genetic studies indicate that a complete hydatidiform mole has a normal diploid karyotype of 46XX, and has proven malignant biologic potential. **Note:** This type is usually entirely derived from the father. A partial mole, is karotypically abnormal; triploidy is the most prevalent abnormality. **Sonographic findings:** Its appearance varies with gestational age. The classic hydatidiform mole has the following **sonographic characteristics:**

"Snowstorm" appearance. Moderately echogenic soft tissue mass filling the uterine cavity, and studded with small cystic spaces representing hydropic chorionic villi. It may only be specific for a second-trimester mole.

First trimester molar pregnancy:
Sonographic identification of the disease in the first trimester has been considered difficult. The appearance of first-trimester molar pregnancy may simulate the following: Missed abortion, incomplete abortion, blighted ovum, hydropic degeneration of the placenta, it may also show a small echogenic mass filling the uterine cavity without the characteristic vesicles. **Treatment:** Primary treatment is uterine curettage followed by serial measurements of serum HCG levels. The serum HCG level falls toward normality within 10 to 12 weeks post evacuation. The reported incidence of residual disease after curettage is approximately 20%. The use of ultrasound during the curettage procedure has been shown to substantially reduce the incidence of residual gestational trophoblastic disease.





Nuchal Translucency:

An important part of the late first trimester sonogram is evaluation of the thickness of the posterior nuchal translucency. This is a thin membrane found along the posterior neck of most embryos beginning at approximately 10 weeks, and is measured up to 14 weeks. An anteroposterior measurement of $\geq$ 3 mm, measured from the membrane to the skin surface, is abnormal. Because an extended fetal neck will result in a falsely increased measurement, the nuchal translucency should always be measured with the fetal neck in neutral position. Another false-positive result to avoid is when the unfused amnion is mistaken for the posterior edge of the nuchal translucency. The significance of an abnormally thick nuchal translucency is increased risk for aneuploidy, or abnormal karyotype.

Chromosomal defects:
The most commonly encountered abnormalities are trisomy 21, trisomy 18, and Turner's syndrome. The nuchal translucency tends to be larger in Turner's syndrome fetuses than in those with other types of aneuploidy. When there is a thickened nuchal translucency and a normal karyotype, the fetus remains at risk; as many as 27% demonstrate a wide range of congenital malformations, in particular congenital heart disease.
Chromosomally normal fetuses, with thickened nuchal translucency measurements at 10 to 14 weeks gestation, have an increased risk of major cardiac anomalies, diaphragmatic hernia, anterior abdominal wall defects and skeletal anomalies.

Growth Assessment:

Intrauterine growth restriction (IUGR):

Best described as a decreased rate of fetal growth. It is most commonly defined as a fetal weight at or below 10% for a given gestational age. It complicates 3% to 7% of all pregnancies. Difficult at times to discriminate between a fetus that is normally small (small for gestational age SGA) and one that is growth restricted. IUGR babies are at a greater risk of antepartum death, perinatal asphyxia, neonatal morbidity, and later developmental problems. Before abnormal growth can be diagnosed it is necessary to accurately determine the gestational age of the pregnancy. In the prenatal period, an accurate last menstrual period or a first-trimester ultrasound can be used. If a first-trimester ultrasound was not performed, second or third trimester sonograms coupled with the standard BPD, HC, AC, and FL should be used. An early diagnosis of IUGR and close fetal monitoring (BPP, Doppler, and fetal growth evaluation) is of significant help in managing a pregnancy suspected of IUGR.

Two types (symmetric and asymmetric):

Symmetric: is characterized by a fetus that is small in all physical parameters (e.g., BPD, HC, AC, and FL). This abnormality is usually the result of a severe insult in the first trimester. The causes may include: Low genetic growth potential, intrauterine infection, severe maternal malnutrition, fetal alcohol syndrome, chromosomal anomaly, or severe congenital anomaly.

Asymmetric growth restriction: is the more common IUGR and is usually caused by placental insufficiency. Placental insufficiency may result from the following: Diabetes or chronic hypertension, cardiac or renal disease, abruptio placenta, multiple pregnancy, smoking, poor weight gain, drug usage, IUGR fetuses have been born to mothers that have **no** high-risk factors. **Note:** All pregnancies undergoing ultrasonic examinations should be evaluated for IUGR.

Sonographic indicators for IUGR: is characterized by an appropriate BPD and HC with a disproportionately small AC. This reinforces the head-sparing effect, which states that the last organ to be deprived of essential nutrients is the brain. BPD and HC may be slightly smaller, but this usually does not happen until the late third trimester.

Biparietal diameter (BPD) – It is not a very reliable predictor of IUGR, for many reasons:

Head-sparing effect is associated with asymmetric IUGR.

Note: Fetal blood is shunted away from other vital organs to nourish the fetal brain, giving the fetus an appropriate measurement for the true gestational age. Second reason is the potential alteration in fetal head shape secondary to oligohydramnios.

Abdominal circumference (AC) – Because of the variability of fetal proportion and size the AC is a poor predictor of gestational age but is very valuable in assessing fetal size.

Note: In IUGR the fetal liver is one of the most severely affected body organs, which alters the circumference of the fetal abdomen.

Head circumference/Abdominal circumference ratio (HC/AC ratio) - It is especially useful in differentiating symmetric and asymmetric IUGR. For each gestational age, a

ratio is assigned with standard deviations. In an appropriate-for-gestational-age (AGA) pregnancy the ratio should decrease as the gestational age increases.

Note: In the presence of IUGR and with the loss of subcutaneous tissue and fat, the ratio increases. HC/AC ratio is at least 2 standard deviations above the mean in approximately 70% of fetuses affected with asymmetric IUGR. The HC to AC ratio is not very useful in predicting symmetric IUGR, since the fetal head and the fetal abdomen are equally small.

Estimated fetal weight (EFW):

The most reliable EFW formulas incorporate all fetal parameters, such as BPD, HC, AC, and FL.

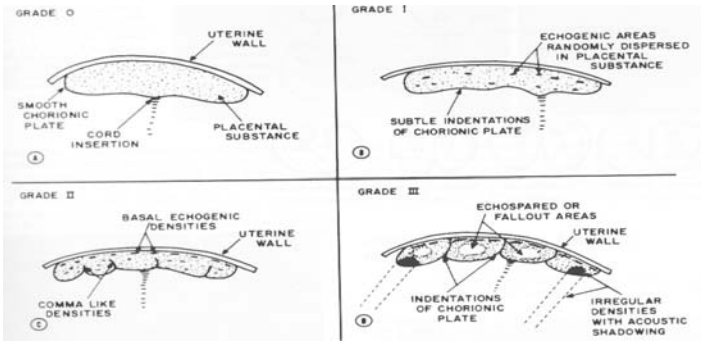
Note: This is important because an overall reduction in the size gives a below-normal estimated fetal weight. An estimated fetal weight below the tenth percentile is considered by most to be at risk for IUGR.

Growth curves:

Numerous growth curves are available. **Note:** The one chosen must be appropriate for the population of patients. The interval growth can be plotted on a graph to show the growth sequence. It is a very helpful tool in following serial exams on the same patient with suspected IUGR. Ethnicity, previous obstetric history, paternal size, fetal gender, and the results of tests of fetal well-being must be considered before IUGR can be diagnosed rather than a healthy SGA.

Amniotic fluid evaluation:

The association between IUGR and decreased amniotic fluid (oligohydramnios) is well recognized. AFI is normal if it is greater than 5 cm and less than 24 cm, with an average of 13 cm ± 5 cm after 24 weeks. Oligohydramnios has also been associated with fetal renal anomalies, rupture of the intrauterine membranes, and the postdate pregnancy.



Placental grade: (Two key ultrasonic markers may help diagnose IUGR)

A grade 3 placenta noted prior to 36 weeks. Decreased placental thickness (less than 1.5 cm).

Tests of fetal well-being – Some other tests that may be incorporated into an IUGR work-up are:

Biophysical profile
Doppler evaluation
Stress/Non stress test

Macrosomia: has been defined as a birth weight of 4000 g or greater or above the ninetieth percentile for its estimated gestational age. With respect to delivery, however,

any fetus that is too large for the pelvis birth canal is macrosomic. It has been shown to be 1.2 to 2 times more frequent in women who have one or more of the following:

- Multiparous
- 35 years or older
- Prepregnancy weight over 70 K
- Pregnancy weight gain of 20K (44 lbs.) or more
- Postdate pregnancy
- History of delivering a large for gestational age fetus (LGA)
- Maternal diabetes - poorly controlled maternal diabetes mellitus is the most common cause of macrosomic babies.

Note: 25% to 45% have maternal diabetes mellitus. Increased levels of glucose promote accelerated somatic growth. Macrosomic infants of insulin-dependent diabetic mothers are usually heavy and show a characteristic pattern of organomegaly. In addition to adipose tissue, the liver, heart, and adrenals are disproportionately increased in size. Increased risks of morbidity & mortality as a result of the following: Head and shoulder injuries, cord compression, clavicular fractures, facial and brachial palsies, meconium aspiration, neonatal hypoglycemia

Sonographic indicators for macrosomia:

BPD– Most investigators believe that BPD is not the optimal parameter to use to predict macrosomia.

AC - It is probably the single most valuable biometric parameter used in assessing fetal growth.

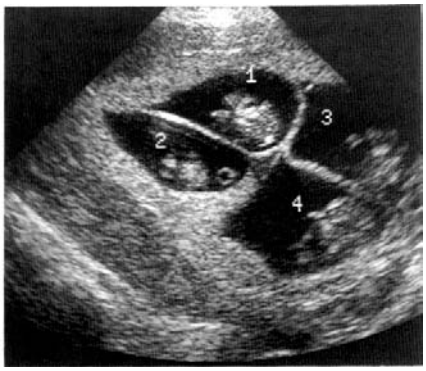
Some studies have shown that an increase in the AC measurement of greater than or equal to 1.2 cm per week (between the 32^{nd} and 39^{th} week) is a highly predictive indicator. Macrosomia may also be indicated in fetuses measuring ***less*** than 4000 g that have normal BPD values, if their AC values are greater than two standard deviations above the normal after 28 to 32 weeks.

Estimated fetal weight - many physicians believe that this calculation is of some value, however, there is a significant number of false positives. False negatives and false positives can be expected unless the actual weight is either less than 3600 g or greater than 4500 g.

Femur length/AC ratio - They are only able to predict 63% of fetuses that are macrosomic, which suggests that this ratio has a limited clinical application. Current studies fail to show a significant increase in the length of the femur in the macrosomic infant.

Other indicators - The placentas of the macrosomic fetus can become significantly large and thick because they are not immune to the growth-enhancing effects of fetal insulin. Mothers with diabetes may accumulate more amniotic fluid (polyhydramnios) than nondiabetic patients.

High Risk Pregnancy



Multiple Gestations:

The mother with a multiple gestation is at increased risk for obstetric complications, such as:

- Preeclampsia
- Third-trimester bleeding
- Prolapsed cord
- Premature delivery
- Congenital anomalies

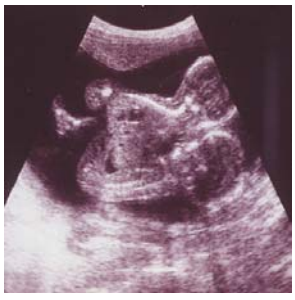
Statistics/Indications:

A twin has a five times greater chance of perinatal death than a singleton fetus. Physicians follow multiple gestations closely with ultrasound. **Note:** Before ultrasound was used routinely, as many as 60% of twins were not diagnosed before delivery.

Review (2 types of twins)

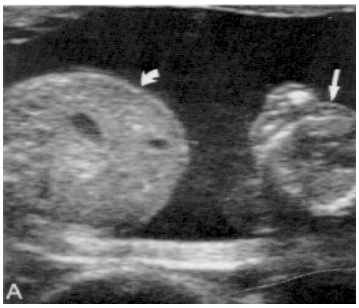
1) Dizygotic - this type of twin pregnancy arises from two separately fertilized ova. Each ovum implants separately in the uterus and develops its own placenta, chorion, and amniotic sac (diamniotic, dichorionic).

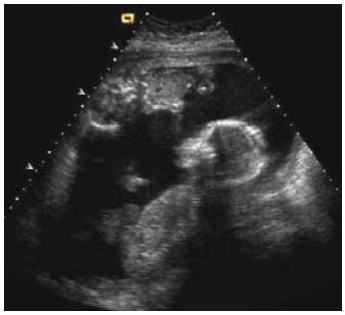
2) Monozygotic (Identical) single fertilized egg, which divides, resulting in two genetically identical fetuses. Depending on whether the fertilized egg divides early or late, there may be one or two placentas, chorions, and amniotic sacs.



Conjoined twins - if division occurs after 13 days, the division may be incomplete and conjoined twins may result. The twins may be joined at a variety of sites, including head, thorax, abdomen, and pelvis. Monozygotic twins present a very high-risk situation. Besides being associated with an increased incidence of fetal anomalies, if there is only

one amniotic sac, the twins may entangle their umbilical cords, cutting off their blood supply. Since monozygotic twins may share a placenta, they are at increased risk for a syndrome known as twin-to-twin transfusion.





Twin-to-twin transfusion - This exists when there is an arteriovenous shunt within the placenta. **Note:** The arterial blood of one twin is pumped into the venous system of the other twin.
Donor twin - It becomes anemic and growth-restricted. This twin has less blood flow through its kidneys, urinates less, and develops oligohydramnios.
Recipient twin - This twin gets too much blood flow. It may be normal or large in size. This fetus has excess blood flow through its kidneys and urinates too much, leading to polyhydramnios. This twin may even go into heart failure and become hydropic.
Complications: When oligohydramnios exists in one sac and polyhydramnios in the other, the small twin may appear stuck in position within the uterus, hence the term stuck-twin. The growth of the twins will be discordant, with the donor twin falling off the growth curve. Both twins are at risk of dying, the smaller one because it is starving to death and the larger one because of heart failure. **Note:** The obstetrician may be forced to deliver the fetuses early if it appears that one or both of the twins are at risk of dying in utero. Fetal surveillance is increased when growth discordancy, oligohydramnios, or polyhydramnios is discovered.

Sonographic considerations with multiples: The sonographer should always attempt to determine the number of amniotic sacs by locating the separating membrane(s). **Note:** If two sacs are seen, the pregnancy is known to be diamniotic, but the sonographer will not be able to determine whether the twins are identical. An attempt should also be made to determine the number and location of the placentas. Occasionally, clearly separate placentas may be identified. If the two placentas are implanted adjacent to each other or fused, it may be difficult to determine if there are one or two placentas. The twins should each then be scanned for corroboration of dates and size. Since the growth of twins is similar to that of singletons early in pregnancy, singleton growth charts are generally used. Twins are usually smaller in size at birth than singleton fetuses of comparable gestational age. The following measurements have been reported as predictors to discordant growth between twins: A difference in estimated fetal weight of more than 20%. A difference in AC of 20 mm. A difference in femur length of 5 mm. The gender of the fetuses is also important to determine. Twin-to-twin transfusion cannot exist in twins of the opposite sex. If both twins are of the same sex and growth discordancy exists, twin-to-twin transfusion syndrome may be a possibility.

Immune and nonimmune hydrops

Immune hydrops:

Process results when fetal red blood cells obtain entry into the maternal blood system. The fetal red cells possess antigens to which the mother, lacking that antigen, mounts an immune response. The resulting antibody can cross the placenta because of its small size.

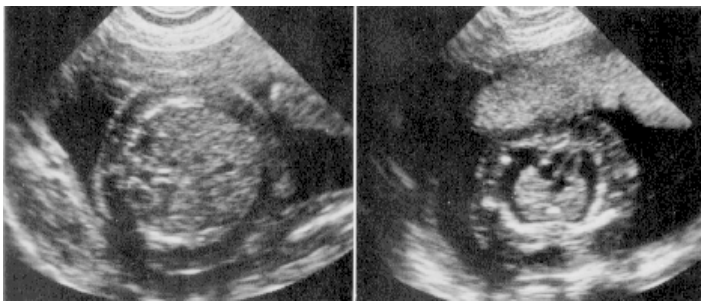
Note: It attaches to the fetal red blood cell and destroys the fetal red blood cell (hemolysis). This hemolysis then results in fetal anemia, and the fetal bone marrow must then replace the destroyed red blood cells. If the production of red blood cells cannot keep up with the destruction, the anemia can become severe and congestive heart failure and edema of fetal tissues may occur.

Identification and treatment: Maternal ABO and Rh determination and antibody screening during pregnancy diagnose blood group isoimmunization. Once an antibody known to cause hydrops fetalis has been identified, the antibody titer must be determined. If the antibody titer is less than 1:16, intrauterine death is unlikely. If the antibody titer is greater than 1: 16, the pregnancy should be monitored. The severity of fetal anemia can be determined by two methods, amniocentesis, the older method, and cordocentesis, the newer method. If the fetus is shown to be severely anemic, the treatment is usually blood transfusion.

Sonographic findings: In examining a fetus for signs of hydrops the sonographer is looking for signs of edema. **Note:** Scalp edema may also be present.

The fetus may also have the following sonographic signs:

- Ascites
- Pleural effusions
- Pericardial effusion
- Polyhydramnios
- The placenta will be large and thick because the liver and spleen are involved in producing red blood cells, they will be large.



Nonimmune hydrops (NIH):

It is a term used to describe a group of conditions in which hydrops is present in the fetus but is not a result of fetomaternal blood group incompatibility. Numerous fetal, maternal, and placental disorders are known to cause or be associated with NIH, including the following: Cardiovascular, chromosomal, hematologic, urinary, and pulmonary problems, twin pregnancies, malformation syndromes, and infectious diseases. Cardiovascular lesions are often the most frequent causes of NIH. Diagnosis is confirmed with a negative blood group incompatibility test and sonographic signs of hydrops. Many times an etiology for NIH cannot be determined. If an etiology is found, treatment depends on the cause.

Sonographic findings: NIH appears identical to immune hydrops.

Diabetic patient:

Diabetic pregnancies may be complicated by frequent hospitalizations for glucose control, serious infections such as pyelonephritis, and problems at the time of delivery. If glucose levels are very high and uncontrolled, the fetus may have many problems.
Note: Macrosomia is the most common. There are two types of diabetes, insulin-dependent (IDDM) and noninsulin-dependent or diet-controlled (NIDDM). Some pregnant diabetics may show signs of diabetes only during pregnancy and have normal glucose levels when they are not pregnant (i.e., gestational diabetics). **Note:** Gestational diabetics may be diet-controlled or require insulin. Pregnancy dates should be confirmed with ultrasound. Because of unexplained stillbirth and pregnancy complications, the physician may elect to deliver the diabetic at 38 to 40 weeks.
Note: The physician may also elect to deliver when fetal lung maturity is demonstrated. Correct dating is very important! A preterm baby delivered from a diabetic mother may end up in the high-risk nursery with respiratory distress syndrome. **Sonographic signs** of poor glucose control: Polyhydramnios, fetus measuring large for gestational age, increased adipose tissue may be seen on the fetus in utero, associated fetal anomalies, caudal regression syndrome (lack of development of lower limbs). **Note:** It is seen almost exclusively in diabetics.
Congenital defects of the heart and neural tube defects.

Hypertension:

It is a medical complication of pregnancy that occurs frequently in high-risk populations. Hypertensive pregnancies may be associated with the following: Small placentas because of the effect of the hypertension on the blood vessels. If the placenta develops poorly, the blood supply to the fetus may be restricted and IUGR may result. **Note:** Growth restricted fetuses are at increased risk of fetal distress and death in utero.
Hypertension is clinically categorized as two hypertensive states during pregnancy, *pregnancy induced, and chronic hypertension.*
Pregnancy-induced hypertension: (which includes preeclampsia, severe preeclampsia, and eclampsia)
Preeclampsia: is a pregnancy condition in which high blood pressure develops with proteinuria (protein in the urine) or edema (swelling). If the hypertension is neglected, the patient may develop seizures that can be life threatening to both mother and fetus.
Severe preeclampsia: May develop in some cases and refers to the severity of hypertension and proteinuria. This condition generally indicates the patient must be delivered immediately.
Eclampsia: represents the occurrence of seizures or coma in a preeclamptic patient.
Chronic hypertension: is present before the woman becomes pregnant. It is diagnosed in patients in whom high blood pressure is found before 20 weeks gestation.
Sonographic findings: The ultrasound team may be called on to perform serial scans for fetal growth and to monitor for the adequacy of amniotic fluid. If fetal growth is falling off the normal growth curve or oligohydramnios occurs, the obstetrician may intervene and deliver the fetus. **Note:** This finding may be a precursor to intrauterine fetal demise. Hypertensive pregnancies are also associated with abruptio placenta.

Placental abnormalities:

Placental abruption:

It is where the placenta separates from its site of implantation in the uterus before the delivery of the fetus. If the majority of the placenta separates from the uterus, fetal death follows if the fetus is not delivered immediately (1 in 500 deliveries).

Common causes:

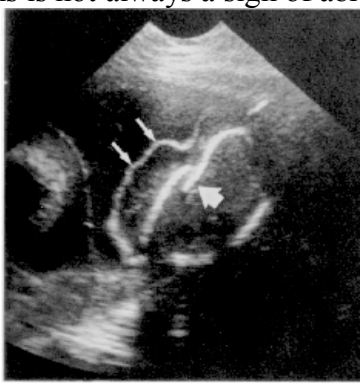
- Abdominal trauma
- Short umbilical cord
- Sudden decompression of the uterus
- Pregnancy-induced hypertension

Clinical indications – It is a diagnosis made clinically and usually presents with one or more of the following symptoms:

- Pre term labor
- Vaginal bleeding
- Abdominal pain
- Fetal distress or a dead fetus
- Uterine irritability

Often when a patient is "abrupting," the uterus is "rock-hard" to palpation.

Difference between placenta previa and placental abruption – they both present with third-trimester bleeding; previa is usually associated with painless bleeding and the abruption is associated with pain. **Sonographic findings:** On ultrasound examination, a cystic area may be seen retroplacentally. In early pregnancy, elevation of the membranes may be seen. **Note:** This is not always a sign of abruption.



Fetal death:

It may occur in any trimester of pregnancy. The incidence of pregnancy loss in the first trimester is between 15 and 20 per 100 pregnancies. **Note:** Most of the losses result from cytogenetic abnormalities. As the pregnancy progresses into the second and third trimester, the incidence of fetal death decreases (between 5 and 10 per 1000 pregnancies). **Note:** Most of the losses result from non-cytogenetic abnormalities.

Clinical indications:

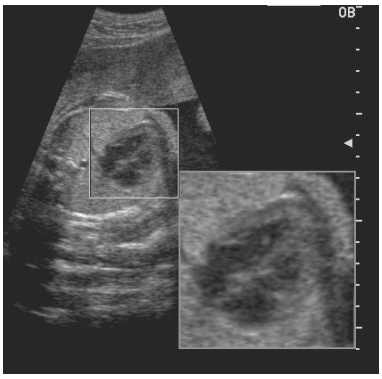
First trimester clinical symptoms - vaginal bleeding, cramping, or passage of tissue. Ultrasound examination may reveal a blighted ovum or a fetus with no heart motion.

Second trimester clinical indications – Failure to achieve any one of the following landmarks may prompt the clinician to obtain an ultrasound examination: Fetal heart tones should be heard with Doppler at approximately 12 weeks gestation. The uterine fundal height should have risen to the umbilicus and the uterus should measure

approximately 20 cm above the symphysis pubis at 20 weeks gestation. The mother should also perceive fetal movements on a daily basis beginning somewhere between 16 and 20 weeks gestation. **Sonographic findings**: The following sonographic signs are usually present with fetal demise:

- Absence of fetal heart motion
- Overlapping of skull bones (Spalding's sign) caused by liquefaction of the brain
- An exaggerated curvature of the fetal spine
- Gas in the fetus

Other than an absent fetal heart beat, these signs require several days to develop.
Note: If present, they indicate that the baby has been dead for more than 48 hours. There may be other ultrasound findings that may indicate the cause of death. The presence of severe oligohydramnios may indicate that intrauterine growth restriction or renal anomalies may have been present. Fetal ascites may indicate the presence of blood group isoimmunization or NIH.



Fetal heart:
Technique and Normal Anatomy:

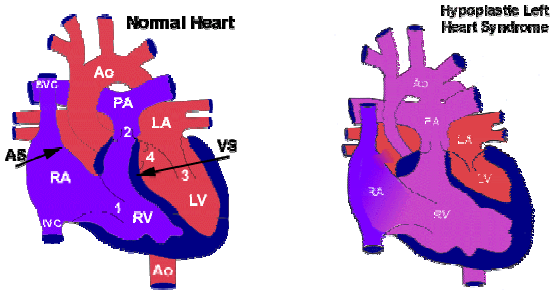
- Four Chamber View
    - Document situs- heart apex should be pointing to left side
    - Document 4 chambers.
    - Document the interventricular septum 45 degrees.
    - Evaluate heart size- should occupy about one third of the fetal thorax.

Six questions you should ask when evaluating the heart:
Is the heart in the normal position? Is the heart normal in size in comparison with the fetal thorax? Are the ventricular chambers about equal in size? Is there a septal defect? Are the atrioventricular valves in normal position? Is there an abnormality of the endocardium or myocardium?

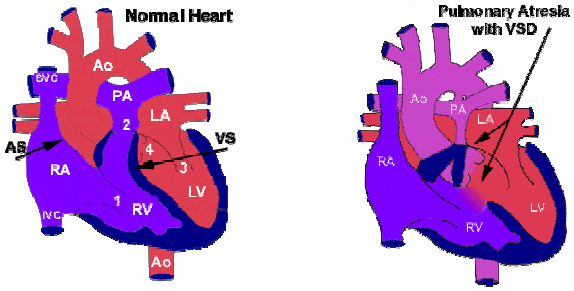
Ultrasound Pitfalls:
Septation within the atrium

- Bright spot apex of ventricle
- Pseudoventricular Septal Defect
- Pseudopericardial Effusion
- Echogenic focus left ventricle - represents calcifications in the papillary muscle; normal finding usually but has an association with Down's syndrome.

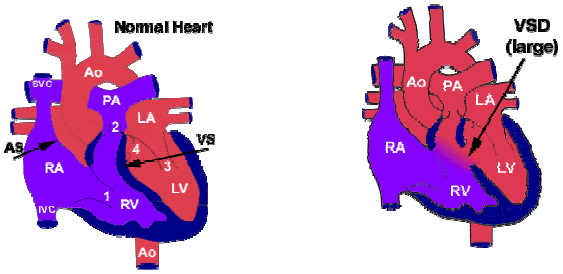
Major Cardiac Malformations:



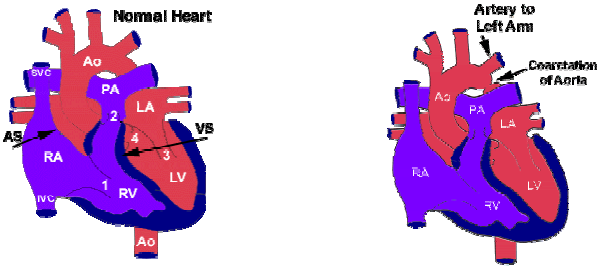
Hypoplastic Left Ventricle - Left ventricular hypoplasia is one of the most commonly seen major congenital cardiac defects. Considered lethal anomaly. Findings - enlarged right ventricle and very small left ventricle.



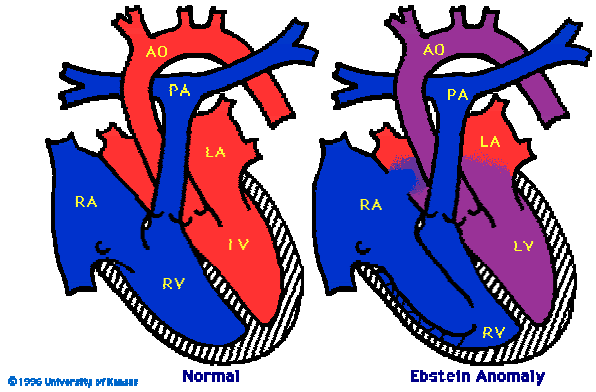
Pulmonary atresia - the right atrium is markedly enlarged and the heart fills almost the entire chest. The left atrium is normal in size but deformed probably by pressure from the enlarged right atrium.



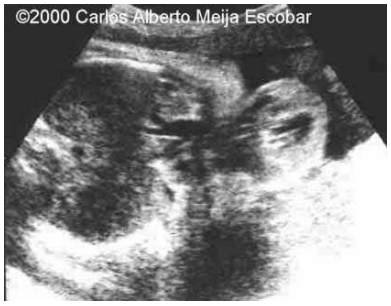
Ventricular septal defect



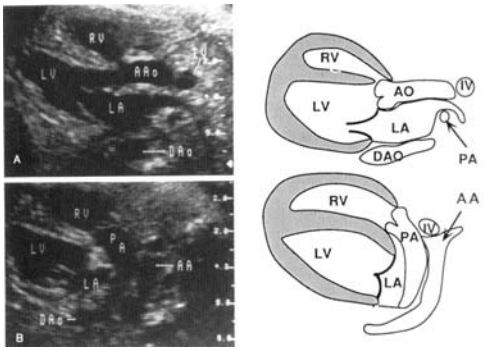
Coarctation of the aorta - narrowing of aortic arch between left subclavian artery and entrance of the ductus arteriosus. Fetal coarctation of the aorta may also be indicated by an enlargement of the right ventricle.



Ebstein's anomaly - the relationship of the left ventricle to left atrium in normal. However, the right ventricle is atrialized by the malposition of the septal tricuspid valve leaflet deep in the right ventricle.



Ectopia Cordis- Heart outside the chest wall.



Outflow Tracks

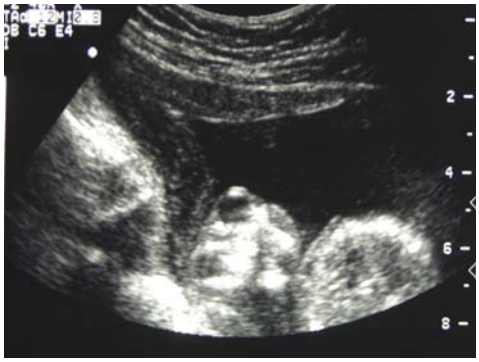
Five Chamber view - From the four-chamber view, the transducer can be moved cranially to obtain a five-chamber view. This view demonstrates the aortic root and the pulmonary artery as it arises from the right ventricle. Angle towards the left fetal shoulder. ***Criteria:*** Great arteries should course nearly perpendicular to each other. The pulmonary artery, should be anterior and to the left of the aortic root. The pulmonary artery, the diameter of which is slightly larger than the aortic root.

Long view of aortic Arch - should demonstrate the ascending and descending aorta and the aortic arch, including the three major neck vessels: the left carotid, left subclavian, and the brachiocephalic arteries. **Note:** The aorta originates from the left ventricle- with transposition, the aorta is connected to the right ventricle and the pulmonary artery is connected to the left ventricle.

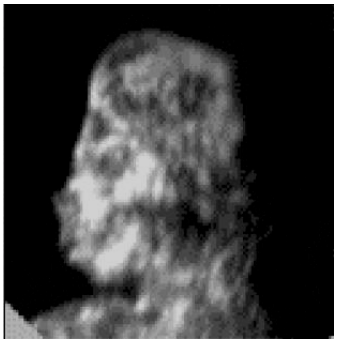
Prenatal Diagnosis of Congenital Anomalies

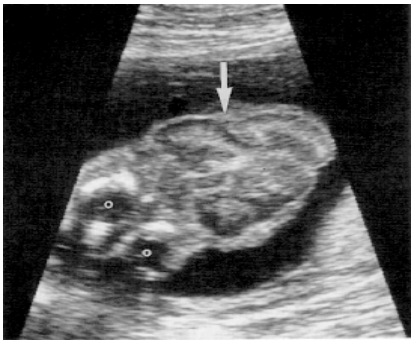
Targeted ultrasound:
It is defined as a specialized sonographic survey of the fetus at risk for specific congenital anomalies based on family history or a fetal anomaly diagnosed during pregnancy. Targeted surveys attempt to: Detect or confirm a congenital anomaly. Assess the fetus at risk for a fetal anomaly. Clinically follow the progression of a congenital anomaly during the gestation period.
Clinical indications: Family history or prior birth defect of a child with a congenital anomaly. Suspected or known congenital anomaly. History of chromosomal abnormality associated with a structural anomaly detectable with ultrasound. Basic fetal survey suggestive of a fetal anomaly. Basic fetal survey suggestive of polyhydramnios or oligohydramnios. Abnormal alpha-fetoprotein or equivalent testing. High risk pregnancy with a risk for the development of congenital anomalies. Nonimmune hydrops. Chemical or drug exposure.

Abnormalities of the cranium:

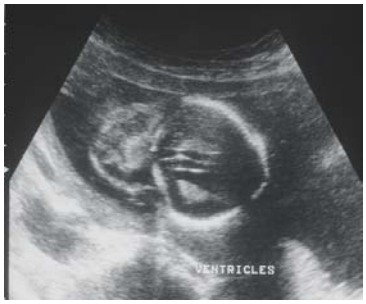


Anencephaly:
It results from failure of the rostral neuropore to close at the cranial end by 38 menstrual days. It is the single most common anomaly affecting the skull and brain. **Note:** 1 per 1500 births. It results in only partial formation of the forebrain followed by degeneration, which leaves only the presence of the brain stem, midbrain, and skull base. The fetus has a normal midbrain and posterior fossa, but lacks normal development of the cerebral hemisphere. A tissue called angiomatous stroma or cerebrovasculosa covers the remnant brain. It is a lethal disorder and an early diagnosis is preferred. **Note:** MSAFP levels are exceedingly high with this defect because of absent skull and exposed tissue.
Causes - It may be part of a syndrome resulting from a single defect or occur with a chromosomal abnormality. Teratogenic insult (chemical exposure) Maternal diabetes mellitus Hyperthermia (hot saunas). **Sonographic findings:** absent skull or brain above the orbits. Rudimentary brain tissue herniating from the open defect. Bulging fetal orbits from the absent frontal bone. Polyhydramnios occurs in 50% of the cases after 25 weeks gestation. **Note:** This condition occurs because of depressed or ineffective swallowing, excessive urination, or reabsorption, deficiencies of cerebrospinal fluid, increased fetal activity because of irritative effects of exposed meninges and neural tissue.





Acrania (Exencephaly): is a serious malformation that occurs because of abnormal migration of mesenchymal tissue, which normally covers the cerebral hemispheres. **Note:** This faulty migration results in faulty formation of the cranial bones, muscles, and dura matter. As in anencephaly, the fetal cranium is absent; however, unlike anencephaly, brain tissue is always present. It occurs more infrequently than anencephaly, and in some cases, it is the embryonic precursor to the development of anencephaly. **Note:** When the open brain tissue gets exposed to amniotic fluid, it gets destroyed and becomes the rudimentary brain found in anencephaly. **Sonographic findings:** Development of brain tissue with no evidence of calvarium. **Note:** In partial acrania, portions of the skull may be observed. Brain tissue may appear to be unorganized and have irregular echogenicities. Prominent sulcal markings, coexisting anomalies include spinal defects, cleft lip and palate, and clubfoot.

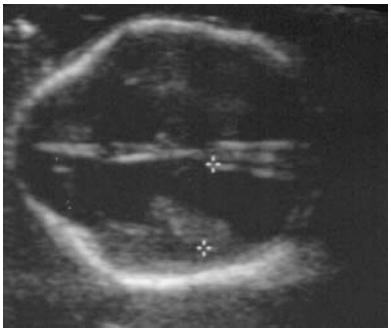


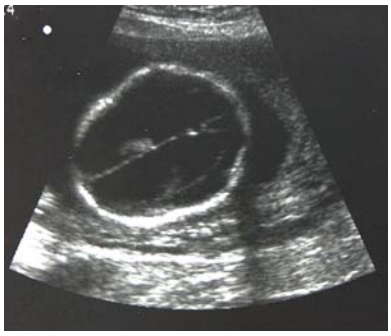
Encephalocele (Cephalocele): are neural tube defects caused by herniation of the brain and/or contents through a defect in the skull. **Note:** Cephaloceles are most commonly either meningoceles or meningoencephaloceles. It occurs in 1 per 2000. It occurs because of a congenital defect in the skull. It most commonly involves the occipital bone and is usually located midline. **Sonographic findings:** Its sonographic appearance largely depends on its location, size, and involvement of brain structures. The following abnormalities are usually observed: an extracranial mass, ventriculomegaly, and bony defect in the skull. **Note:** The diagnosis can be made with certainty only if a bony defect in the skull is detected. Coexisting anomalies and syndromes are common with cephaloceles. **Note:** The sonographer should closely evaluate the following areas to help predict the severity of the disease: cranium, spine, kidneys, face, and limbs.

Microcephaly: is an abnormally small head caused by an overall reduction in the size of the brain, resulting from a developmental defect of the cerebrum. It is a major clinical concern because it is usually associated with mental retardation. **Note:** 85% of children with microcephaly have mental retardation. Its incidence is 1 per 6200 to 8500 births. **Causes:** Inheritance, chromosomal aberrations, severe prenatal radiation exposure, viral

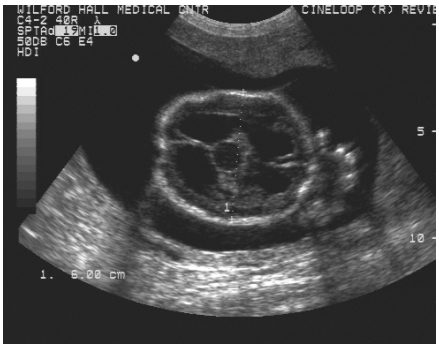
infections (rubella, cytomegalovirus), maternal alcoholism or heroin addiction, mercury poisoning. **Sonographic characteristics suggestive of microcephalus (most common):** Small BPD and HC. **Note:** Fetal head circumference either 2 or 3 SD below the mean of that expected for menstrual age. Head to abdomen disproportion, disorganized brain tissue, intracerebral calcifications suggestive of infection, ventriculomegaly.

Intracranial abnormalities:



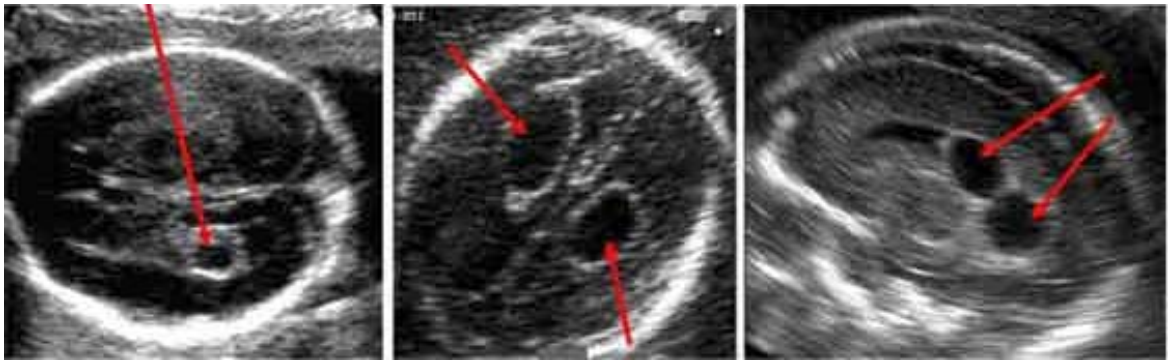


Ventriculomegaly (Hydrocephalus): is dilation of the fetal ventricular system. Enlargement of the ventricles occurs because of an obstruction impeding the normal flow of cerebrospinal fluid. The abnormally enlarged ventricles exert pressure on brain tissue, which may lead to irreversible brain damage. The incidence of occurrence is 0.5 to 1.8 per 1000 births, with the majority having an unknown cause. **Common causes:** Neural tube defects, encephaloceles, Dandy-walker malformations (dilation of the 4th ventricle), agenesis of the corpus callosum (overgrowth of brain tissue), aqueductal stenosis (most common cause), chromosomal disorders. **Sonographic findings:** It typically progresses from the occipital horns into the temporal and then to the frontal ventricular horns. Ventriculomegaly may be quantified by measuring the size of the ventricular atria. **Note:** A dilated ventricle (downside) exceeds 10 mm in diameter. When ventriculomegaly is diagnosed, a targeted examination should be performed to detect any coexisting abnormalities and to determine the extent of the disease.

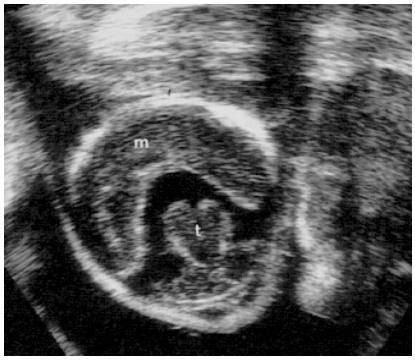


Hydranencephaly: is defined as a failure of the cerebral hemispheres to develop, caused by occlusion of the internal carotid arteries. **Note:** This leads to hemorrhage and infarction of the brain. The occipital lobes, midbrain, basal ganglia, cerebellum, and choroid plexus are spared because of preserved circulation from the posterior communicating arteries. There is no association with coexisting structural or chromosomal abnormalities. **Sonographic findings:** Brain tissue is replaced by a

massive amount of cerebrospinal fluid. The falx is usually present but may be deviated. **Note:** At times, the falx is absent or partially formed. Choroid plexus may be observed. There is a complete lack of cerebral tissue. Macrocephaly occurs as a result of production of cerebrospinal fluid. Polyhydramnios.

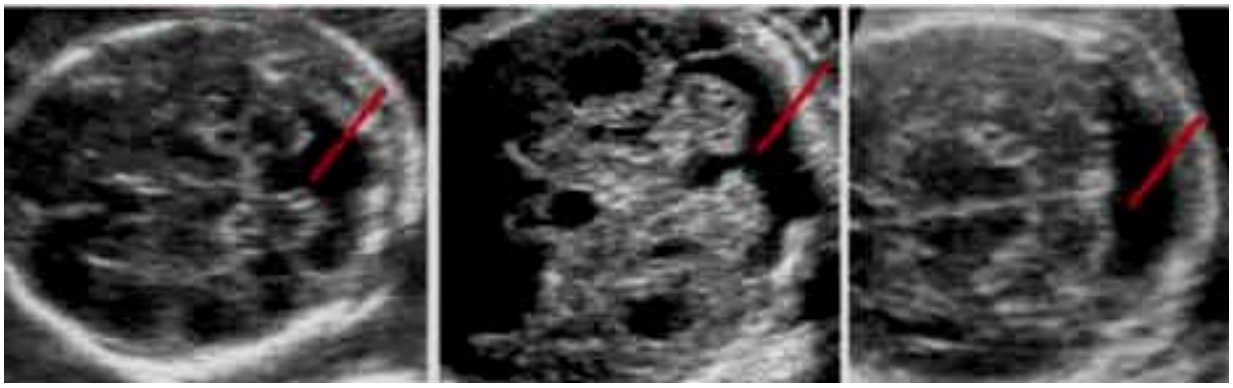


Choroid plexus cysts: are commonly observed during a routine fetal survey in 1% to 2% of normal fetuses. They are usually observed prenatally from 15 to 26 weeks of pregnancy (it is usually resolved by the 24th week). Most represent normal development, however, they be associated with a chromosomal abnormality. **Note:** Most frequent is Trisomy 18. **Sonographic characteristics:** Cyst size ranges from 0.3 to 2 cm. They may be bilateral. They may have irregular or multilocular appearance. Large cysts may cause ventricular expansion. When a cyst is found, surveys to exclude anomalies suggestive of a chromosomal abnormality are recommended. **Note:** If one additional abnormality is detected, amniocentesis should be offered.



Holoprosencephaly: is a group of brain disorders that result from abnormal cleavage of the proencephalon or forebrain. The defect may affect the development of the midline facial plane, causing varying orbital and facial malformations (17% of fetuses). Alobar, semilobar, & lobar are three different forms. **Note:** The specific form depends on the degree of failed hemisphere division. **Sonographic characteristics (most common):**

Alobar holoprosencephaly: Single common ventricle that may appear in a C-shaped pattern because of absent temporal, occipital, and frontal horns. Brain tissue may appear in a cup, ball, or pancake configuration. Fusion of the thalamus, absent third ventricle, and absent falx, presence of a supraorbital proboscis in cyclopia and midline proboscis with ethmocephaly, nasal anomalies, cleft lip and/or palate abnormalities. Chromosomal abnormalities occur in 50% of cases.



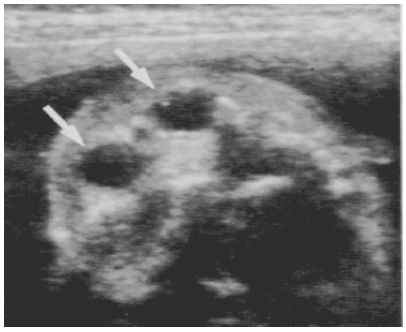
Dandy-Walker malformations: are a defect involving the cerebellar vermis, which may be partially or completely absent. **Note:** This results in a dilated fourth ventricle. The milder form is termed Dandy-Walker variant. This disorder accounts for approximately 5% to10% of cases of ventriculomegaly. **Causes:** There are many causes ranging from various syndromes to teratogenic exposure. S**onographic characteristics (most common):** Cerebellar vermis defect (complete or partial). A posterior fossa cyst representing a dilated fourth ventricle, enlargement of the cisterna magna (representing the fourth ventricle), splaying of the cerebellar hemispheres, ventriculomegaly (80%).

Abnormalities of the face:

Congenital anomalies of the face affect 1 in 600 births. Fetal facial evaluation is not included in a basic fetal scan, however, when there is a history of craniofacial malformation or when a congenital anomaly is found, the face should be screened for a coexisting facial malformation. Facial anomalies often indicate a specific syndrome or condition. Facial anomalies are heterogeneous and can occur as isolated defects or part of a syndrome.

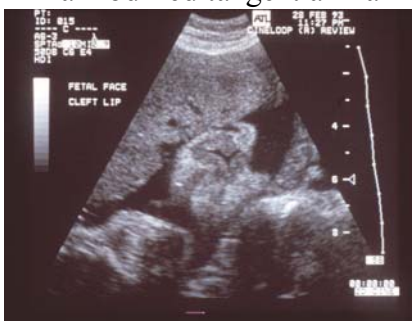
Abnormalities of the facial profile: are achieved by a series of midsagittal scans through the face. The fetal forehead appears as a curvilinear surface with differentiation of the forehead, nose, lips, and chin. This view allows for diagnosis of anterior cephaloceles, which may arise from the frontal bone. Profile views are also often helpful in the study of fetuses at risk for skeletal dysplasias. **Note:** Frontal bossing (a prominent forehead) is characteristic for skeletal dysplasias. Frontal bossing may be observed in a fetus with a lemon shaped skull. **Note:** Usually from spina bifida. Congenital micrognathia may be suspected when a small chin is observed. Tongue protrusion may suggest macroglossia (enlarged tongue). Teratomas may also be detected that can obstruct or impair the swallowing, which will result in polyhydramnios and a small or absent stomach bubble.

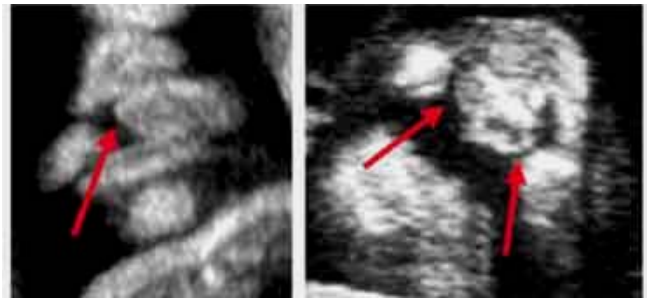
Abnormalities of the orbits: are usually evaluated in the axial plane. Orbital distance measurements are helpful in diagnosing hypertelorism and hypotelorism. Orbital anomalies are associated with multiple disorders and chromosomal abnormalities.



- **Hypotelorism** – Abnormally decreased distance between the orbits. **Note:** Most commonly associated with holoprosencephaly. Generally both the interocular distance (ID) and the binocular distance (BD) fall well below 2 SD of the mean.
- **Hypertelorism –** Abnormally widely spaced orbits. **Note:** Can be an isolated primary defect, or occur secondarily as part of multiple syndromes. It has been reported that hypertelorism is characterized by an inner orbital diameter (IOD) above 2 SD from the mean.
- **Cyclopia** – Fetus containing only one eye.

Abnormalities of the nose and lips Scanning technique: These structures can be evaluated in the coronal plane (most common), sagittal profile plane (least accurate), and in a modified tangential maxillary view.

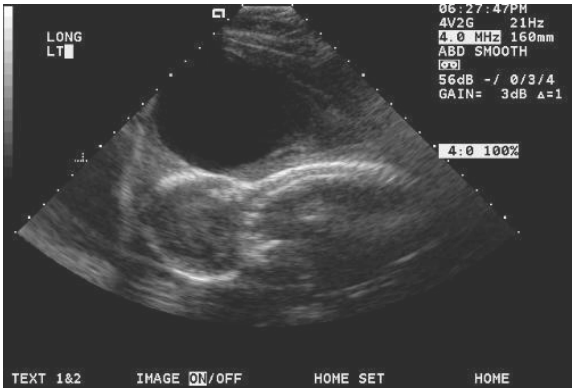




Clefts - Cleft lip with or without cleft palate is the most common congenital malformation involving the face. **Note:** The incidence of cleft lip and palate is about 1 per 1000 among Caucasians. Cleft lip with or without cleft palate results from failure of fusion of the maxillary prominence with the medial nasal prominence on one or both sides. They are best evaluated in the coronal plane. **Note:** The sagittal profile view is sometimes helpful. Often associated, but cleft lip and cleft palate originate at different times during development. **Note:** About 80% of infants with cleft lip also have cleft palate. Clefts are associated with many disorders and chromosomal abnormalities. **Note:** This condition may also exist as a singular birth defect.

Abnormalities of the neck:

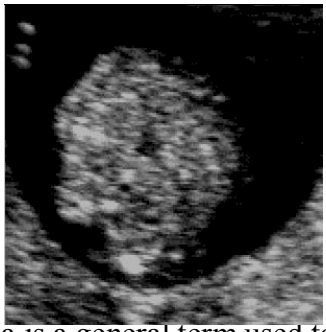
They are rare but when present may represent life threatening disorders. The most common is a cystic hygroma. **Note:** Rarer lesions may include cephalocele, cervical meningomyelocele, goiter, teratoma, sarcoma, or metastatic lymphadenopathy.



Cystic hygroma: results from a malformed lymphatic system. Most likely develops from a defect in the formation of lymphatic vessels. They may be small or large depending on the degree of obstruction and usually appear cystic. When first-trimester cystic hygroma occurs in the presence of normal karyotype, and entirely normal outcome is possible. **Note:** When hydrops is present, the outlook is grave. **Associated disorders:** One of the most common associated disorders is Turner's syndrome, but it is also associated with multiple disorders. Neck teratomas usually have complex sonographic patterns similar to teratomas on other organs. The sonographer should evaluate a neck mass for the following characteristics: Position of mass, unilateral or bilateral position, polyhydramnios is a common finding, heart failure and hydrops, coexisting anomalies (Turner's syndrome).

Abnormalities of the vertebral column:

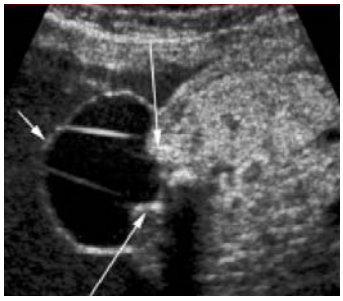
Targeted studies of the spine are indicated by an elevated Maternal Serum Alpha fetoprotein MSAFP, family history of neural tube defect, or when other anomalies such as ventriculomegaly are detected. **Note:** Most departments include a full spinal evaluation as part of their standard pregnancy sonogram.

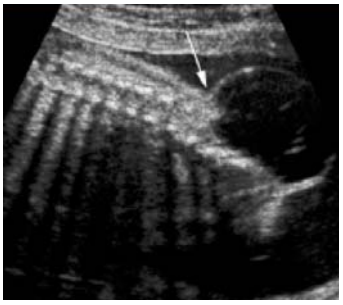


Spina bifida: Spina bifida is a general term used to describe the open forms of spinal dysraphism that result from failure of the posterior neuropore to close. Spina bifida is the most common malformation of cranial and spinal dysraphism. **Note:** The average incidence of spina bifida in the U.S. is about 0.5 to 2 per 1000 births.

Spina bifida occulta: this type of defect is covered by skin and sometimes hair. These lesions are associated with a normal spinal cord and normal neurological development. The skin covering prevents the leakage of alpha-fetoprotein into amniotic fluid or maternal serum.

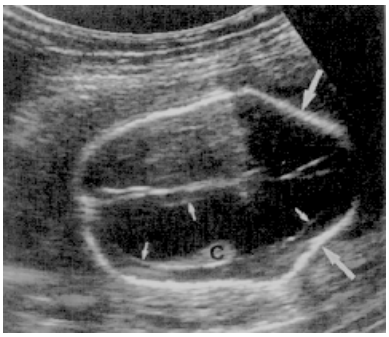
Meningocele: cystic lesions that result from protrusion of the dura and arachnoid through the spinal defect.

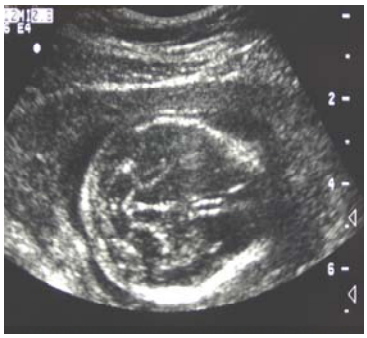




Meningomyelocele: this defect occurs when there is protrusion of both meninges and spinal cord and nerves. It appears as a protruding sac containing echogenic structures representing neural tissue. Neurologic impairment ranges from minor anesthesia to complete paralysis. Secondary cranial malformations are common. **Note:** The most common is Arnold-Chiari malformation, which includes medulla and cerebellum prolapse into the foramen magnum (banana sign) causing ventriculomegaly.

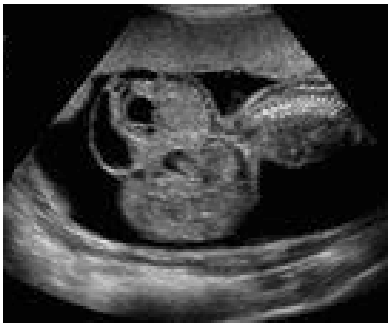
Myelocele or rachischisis: is an extensive and severely exposed open spinal defect. The most common areas for spina bifida are the lumbar region, however, cervical and thoracic defects can occur. **Sonographic appearance:** On transverse sections, each vertebral segment is checked for the circular (O-shaped) configuration of the posterior elements. The spine is checked by a continuous sweep from the cervical vertebrae to sacrum. It is crucial that the transducer be positioned at right angles to the long axis of the spine because improper transducer angles may erroneously suggest a spinal defect. The following are characteristics of an open spinal defect: **Transverse** - splaying of vertebral pedicles (incomplete spinal circle), V, C, or U-shaped appearance or vertebral pedicles, presence of protruding saclike structure, meningoceles (echo free sac), meningomyelocele (meninges and cord within the sac), disruption in the continuity of the covering skin. **Longitudinal -** loss in spinal cord (apparent "break" in spine), widening transverse and absent spinous process, presence of protruding saclike structure, and abnormal spinal curvatures.





Associated abnormalities: The most common extracranial abnormalities are cephaloceles, cleft lip and palate, hypotelorism, hypertelorism. The most common intracranial abnormalities are:

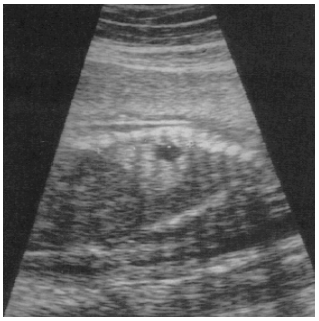
- Ventriculomegaly Effacement of the cisterna magna. **Note:** The cisterna magna rarely appears normal.
- "Lemon-shaped" frontal bones because of frontal bossing. Absent or small cerebellum. **Note:** The cerebellum may resemble a banana. Small head size based on biparietal diameter.
- Malformations of the extremities as a consequence of spina bifida.



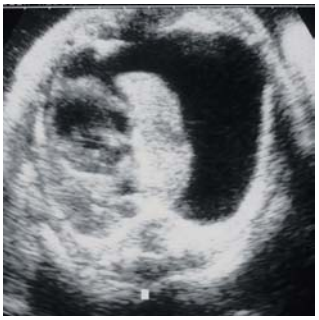
- **Sacrococcygeal teratoma** is a mass arising from the sacrum and coccyx of the fetus. **Note:** They are reported in 1 in 35,000 births, and about 75% occur in girls. They are usually benign and may reach extremely large sizes and interfere with vaginal delivery. Serial sonograms are used to monitor size of the teratoma as rapid increases in size may occur. As with all detected anomalies, a meticulous search for additional malformations is warranted. It may mimic a meningomyelocele, however, meningomyeloceles are largely cystic and teratomas are predominantly soft tissue masses. Hydrops, polyhydramnios, and placentomegaly are commonly associated findings.

Abnormalities of the thoracic cavity

Cystic lung masses:



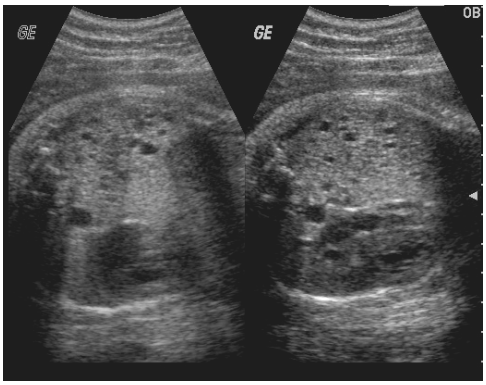
- **Bronchogenic cysts** represent the most common cysts seen prenatally. They result from abnormal budding of the foregut. **Note:** They do not communicate with the trachea or bronchial tree. They are located typically within the mediastinum or lung. They appear sonographically as small circumscribed masses without evidence of a mediastinal shift. **Note:** They are ***not*** usually associated with other congenital anomalies.



- **Pleural effusions (hydrothorax)** are defined as accumulations of fluid within the thoracic cavity that may appear as isolated lesions or secondary to multiple

fetal anomalies. The most common reason for pleural effusion is chylothorax. **Note:** Chylothorax occurs as a right-sided unilateral collection of fluid secondary to a malformed thoracic duct. Pleural effusion may result from immune or nonimmune hydrops or in fetuses with chromosomal abnormalities. **Sonographic appearance:** They appear as anechoic fluid collections in the fetal chest that conform to the normal chest and diaphragmatic contour. Its presence can also cause a shift in mediastinal structures, compression of the heart, and inversion of the diaphragm. Once it has been discovered, a careful search must be performed to attempt to determine the source of the disease.

Solid lung masses



- **Cystic Adenomatoid Malformation (CAM)** is an abnormality in the formation of the bronchial tree with secondary overgrowth of mesenchymal tissue from arrested bronchial development. **Note:** CAM accounts for approximately 25% of congenital lung lesions. Three forms (type I-III)

  Type I – one or several large cysts replace normal lung tissue.
  Note: The single or multiple cysts measure 2-10 cm.

  Type II - they consist of multiple medium-sized cysts that measure less than 1 cm. They are associated with fetal and/or chromosomal abnormalities. The associated anomalies include renal agenesis, pulmonary anomalies, and diaphragmatic hernia.

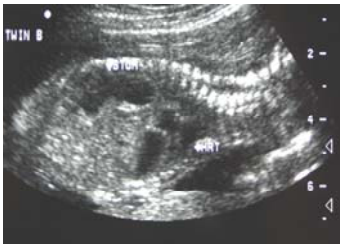
  Type III - multiple microcysts 0.3-0.5 cm. They are characterized by bulky, large, noncystic lesions appearing as echodense masses of the entire lung lobe. They appear solid because of reflections from the walls of the many tiny cysts (similar to infantile polycystic kidneys). Polyhydramnios may be observed secondary to esophageal compression, which is caused by abnormal swallowing. There may be a mediastinal shift.

Prognosis varies depending on the type of the lesion. Type I lesions have favorable outcomes. Type II & III lesions have a poor prognosis. **Sonographic evaluation:** When a cystic or solid lung mass has been identified, the sonographer should attempt the following:

- Determine the number and size(s) of cystic structures
- Check for presence or absence of mediastinal shift
- Look for fetal hydrops
- Exclude cardiac masses

- Search for other fetal anomalies.

Note: Most CAMs are unilateral, without preference for side, and they usually involve one lobe or segment.

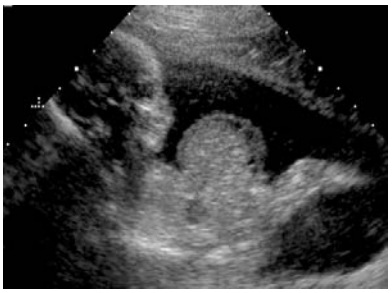


Abnormalities of the diaphragm: Diaphragmatic hernia is a sporadic defect in the diaphragm which allows the abdominal organs to enter into the chest cavity. It occurs in 1 per 3000 to 5000 births and occurs more commonly in females (3:2). It commonly occurs on the left side of the diaphragm, and left-sided organs enter the chest through the opening. The abnormally positioned abdominal organs shifts the heart and mediastinal structures to the right side of the chest. As a consequence of herniated abdominal organs, the lungs are compressed and become hypoplastic.

Sonographic criteria suggestive of a diaphragmatic hernia include the following:

- Shift of heart and mediastinal structures. **Note:** Associated malformations are common, most notably cardiac defects
- Mass within the thoracic cavity
- Small abdominal circumference resulting from herniated abdominal structures.
- Obvious diaphragm defect with intestines in the thorax that demonstrates peristalsis.
- Polyhydramnios
- Over 50% of cases have coexisting structural or chromosomal abnormalities.
- Growth retardation suggests associated anomalies
- An absent stomach bubble

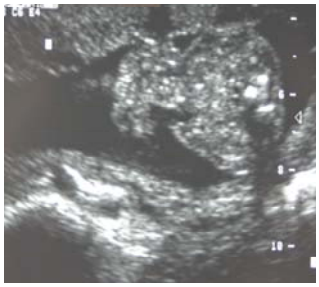
Abnormalities of the anterior abdominal wall (Two common types)

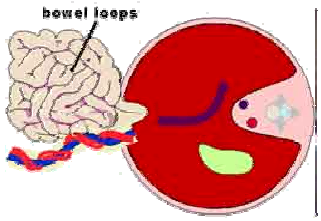


Omphalocele: The incidence is roughly 1 in 4000 live births. This is caused when the fetal bowel fails to return into the abdomen and it stays within the umbilical cord. **Note:** Sometimes a portion of the liver also herniates into the cord. Fetuses with omphaloceles are at a greater risk for chromosomal abnormalities and other anomalies.

Common sonographic signs of omphalocele are as follows:

- Central abdominal wall defect with bowel and/or liver extending into the umbilical cord.
- Membrane composed of peritoneum and forms the omphalocele sac encasing the herniated organs.
- Umbilical hernias may be confused with liver omphaloceles, however, a normal cord insertion suggests hernia.
- Ascites may be present with omphalocele.
- Polyhydramnios is found in 1/3 of fetuses.
- Omphaloceles may occur with diaphragmatic hernia.
- One of the most important prognostic factors in omphalocele is the presence of congenital heart defects.
- Chromosomal anomalies occur in 35% to 60% of cases.

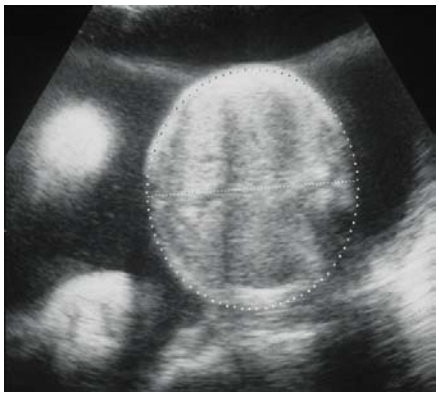




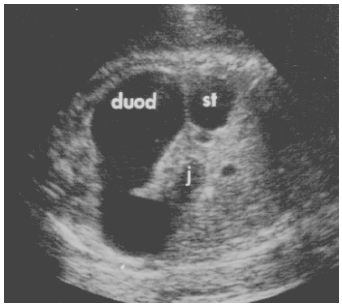
Gastroschisis is an opening in the abdominal wall with herniation of the bowel. **Note:** Infrequently the stomach and genitourinary organs herniate. They are not usually caused by genetic disorders. They are small (2 to 4 cm in size) and are located next to a normal cord insertion. The defect is usually located to the right of the umbilical cord. Alpha-fetoprotein levels are significantly higher than omphalocele because of the absent covering membrane. **Common sonographic indicators:** Right paraumbilical defect of the abdominal wall. **Note:** Left sided defect is very rare. Free floating herniated small bowel. **Note:** Large bowel, stomach, and genitourinary organs may be involved. Herniated bowel may be mildly dilated with bowel wall thickening. **Associated anomalies:** Although genetic associations are rare, bowel ischemia, atresia and perforation can occur. **Note:** Over half of the infants with gastroschisis in which ischemia and gangrene of the bowel are present, subsequently die.

Abnormalities of the hepatobiliary system:
Situs inversus: is a total reversal of thoracic and abdominal organs. **Note:** Partial reversal has been known to occur.
Cholelithiasis (gallstones): have been known to occur in utero but are very rare.

Abnormalities of the gastrointestinal tract (Atresias): is defined as a narrowing or blockage that restricts or entirely blocks the digestive system. When blockage occurs, intestinal loops enlarge above the obstruction and the bowel loops narrow distal to the obstruction. **Note:** Blockage results in a back-up amniotic fluid and polyhydramnios. The three most common sites for atresia are the esophagus, duodenum, and small bowel.



Esophageal atresia: the most common form occurs in conjunction with a fistula communicating between the trachea and esophagus. **Note:** The fistula allows for the passage of amniotic fluid into the stomach. In some instances a fistula will not be present and amniotic fluid will not reach the stomach which results in an absent stomach bubble. **Note:** Esophageal atresia should always be considered when polyhydramnios is accompanied by failure to visualize the stomach bubble.



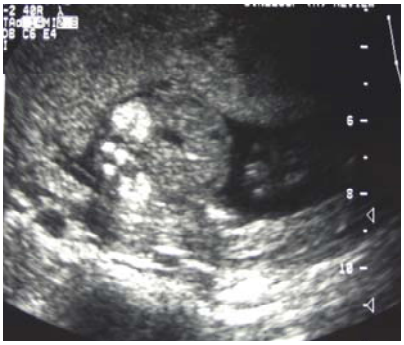
Duodenal atresia: is a blockage of the duodenal lumen by a membrane which prohibits the passage of swallowed amniotic fluid. **Note:** Has an incidence of about 1 in 5000 births and is the most common intestinal obstruction encountered in the perinatal period. Atresia or narrowing of the bowel distal to the obstruction also occurs. **Sonographically**: they appear as two echo free cystic structures seen in the fetal abdomen, which represent the fetal stomach and duodenum; they communicate with one another. **Note:** This is typically called the "double bubble" sign. They have been associated with chromosomal disorders and anomalies. **Note:** Anomalies occur in 50% of cases. 30% have trisomy 21 (Down syndrome). Symmetric growth retardation commonly occurs in fetuses with duodenal atresia.

Bowel obstruction: obstruction can occur in any portion of the GI tract and is associated with many abnormalities. The most common indicator of obstruction is a dilated bowel loop. **Note:** Normal bowel diameter should not exceed 18 mm. The incidence of small bowel obstruction is about 1 in 5000 births. It is difficult, if not impossible, to differentiate a specific location, therefore, it is most accurate to refer to these disorders as small bowel obstructions.

Abnormalities of the urinary tract:

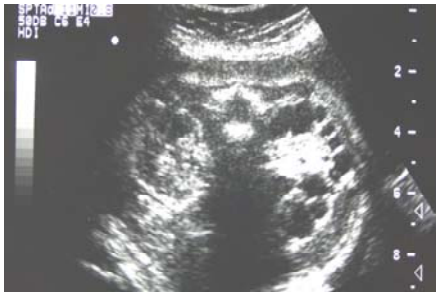
Renal agenesis: is defined as absence of the kidneys. Bilateral agenesis occurs 1 in 4000 births. **Note:** It is a lethal disorder, incompatible with life. Bilateral renal agenesis is known as Potter's syndrome. Unilateral agenesis occurs in 1/500 to 1/1000 births and chances of survival are excellent. **Sonographic findings:** The kidneys and bladder are

unobserved. Accompanied by severe oligohydramnios beyond 16 weeks gestation. The adrenal glands may be large and may mimic the kidneys. **Associated abnormalities**: Many anomalies are associated with this disorder, which directs a targeted study to further explore the condition.



Infantile polycystic kidney disease (IPKD): is an autosomal-recessive disorder that affects the fetal kidneys and liver. The most severe form of the disease is found prenatally. In this disease the collecting tubules of the kidneys are dilated. **Sonographic appearance:** On ultrasound, individual cysts are not identified; instead the kidneys are massively enlarged because of hundreds of dilated tubules. **Note:** Kidney enlargement may not be observed until the 24th week of gestation. The kidneys also become more echogenic because of the multiple interfaces created by the dilated cystic tubules. In the most severe cases of IPKD, renal failure occurs with oligohydramnios and an absent bladder. In some cases the kidneys are so large they fill the entire abdomen. The following characteristics are typical of IPKD:

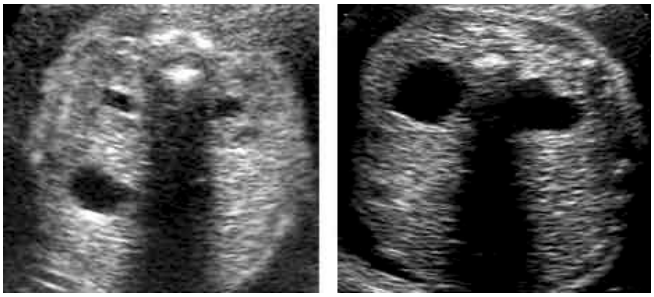
- Family history of IPKD
- Bilaterally enlarged kidneys
- Highly echogenic kidney texture
- Significant oligohydramnios
- Inability to identify the fetal bladder



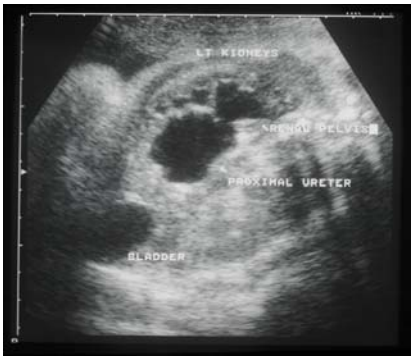
Multicystic dysplastic kidney disease: in this condition, kidney tissue is replaced by cysts of varying sizes that are found throughout the kidney. Kidney borders are difficult to define because of the distorted renal outline. The affected kidney is nonfunctional. **Sonographic appearance:** When multicystic dysplastic kidney disease is detected in one kidney, a thorough study for anomalies of the other kidney should be performed. **Note:** If the contralateral kidney has a normal sonographic appearance, the bladder has normal fluid, and the amniotic fluid is adequate, the other kidney is probably functioning normally. The condition is lethal when both kidneys are affected with this disease and

oligohydramnios is present. There are many associated anomalies with this disease, again, a targeted scan is warranted to rule out any coexisting abnormalities.

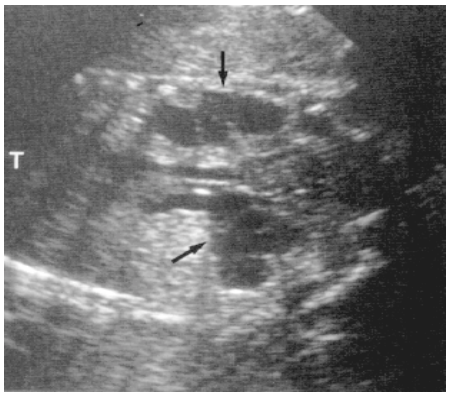
Obstructive urinary tract abnormalities: The urinary tract may be obstructed at the junction of the ureter entering the renal pelvis (ureteropelvic junction) or at the junction of the ureter as it enters the bladder (ureterovesical junction), or at the level of the urethra causing an enlarged bladder (megacystis). The sonographic appearance of urinary tract obstruction varies depending on the site and extent of blockage.



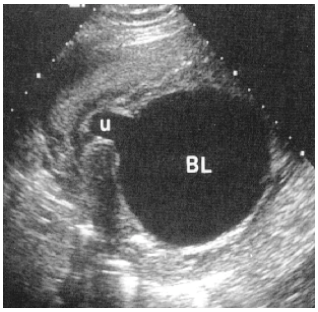
Hydronephrosis: is defined as dilation of the renal pelvis. It occurs in response to a blockage of urine at some junction in the urinary system. It commonly occurs when there is an obstruction in the ureter, bladder, or urethra. **Sonographic appearance:** It is generally the end result of an obstruction in the urinary tract. The ultrasound appearance of hydronephrosis varies according to the severity of the underlying obstruction. The dilated renal pelvis is centrally located and distended with urine, which often communicates with the calyces. **Note:** The remaining renal tissue may be identified in all but the most severe cases of hydronephrosis. It may occur as a unilateral or bilateral process.



Ureteropelvic junction obstruction (UPJ): results from an obstruction at the junction of the renal pelvis and the ureter. It is the most common form of obstructive uropathy, representing fully two thirds of fetal hydronephrosis cases. It is usually a unilateral defect and amniotic fluid remains normal because of the normal contralateral kidney. Anomalies associated with this disorder may involve the presence of a urinoma, which presents as a large cyst that is in contact with the spine. **Note:** Urinary ascites may also be a complicating feature of UPJ obstruction. **Causes are:** 1) Abnormal bends or kinks in the ureter. 2) Adhesions and abnormal valves in the ureter. 3) Abnormal outlet shape at the ureteropelvic junction. 4) Absence of the longitudinal muscle that is imperative to the normal excretion of urine from the kidney.



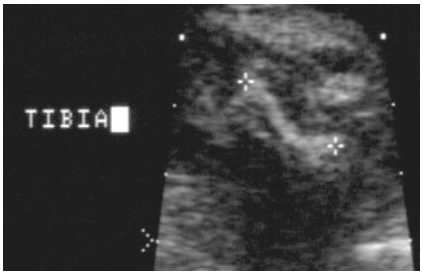
Ureterovesical junction obstruction: commonly presents with dilation of the ureter (megaureter). Megaureter may result from a primary ureteral defect (stenotic ureteral valves or fibrosis). **Note:** Or it can also occur secondary to obstruction at another level (causing reflux or backward flow of urine).



Posterior urethral valve obstruction: results in hydronephrosis, hydroureters, or dilation of the bladder and posterior urethra. It only occurs in males because they only possess posterior urethral valves. This condition causes a back-up of urine in the bladder, ureter, and, in the most severe cases, the kidneys. The following sonographic signs are suggestive of posterior urethral valve obstruction:

- Dilated bladder (thickening of the bladder wall)
- Dilated posterior urethra (key-hole appearance)
- Oligohydramnios
- Hydronephrosis and hydroureters Fetal ascites (some cases)
- Male fetus
- Intermittent posterior urethral valve obstruction may occur with a normal amount of amniotic5 fluid.

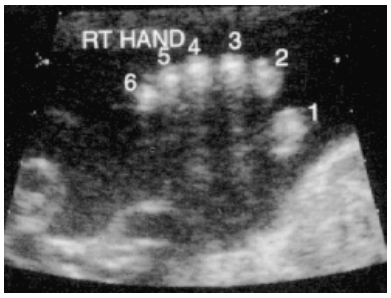
Abnormalities of the extremities:

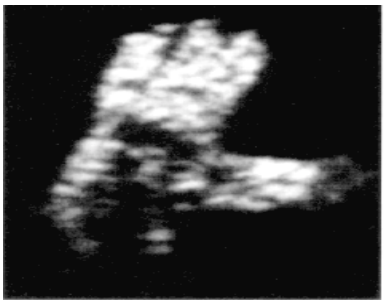


Skeletal dysplasia: is a term used to describe abnormal growth and density of cartilage and bone. There are over 100 forms of skeletal dysplasias, however, very few are

detectable and discernable from each other. **Note:** The role of this section is to introduce you to the sonographic indicators of dysplasias but not the syndromes. **Sonographic detection is dependent upon analyzing the following criteria:**

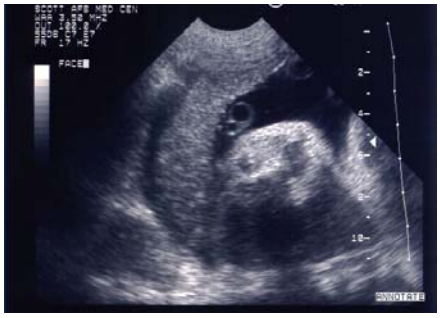
- Define the extent of the limb shortening
- Assess bone contour, thickness, and shape by looking for bowing, abnormal curvature, fractures, and ribbonlike bones.
- Evaluate thoracic cavity size (chest circumference) and shape
- Facial and skull anomalies may indicate a specific dysplasia.
- Survey for existing hand and foot abnormalities. Evaluate spine (mineralization or abnormal curvature)





Common extremity malformations:

1. Polydactyly – An extra digit.
2. Syndactyly – Fingers and/or toes may be missing or fused.
3. Split (Lobster-claw) – Missing fingers with a large separation between the remaining digits.
4. Clubfoot (talipes) – is a developmental defect with abnormal lateral or medial inversion of the foot or feet.
5. Rocker-bottom feet – Prominent heels.



Abnormalities of the umbilical cord:

Two vessel cord - one artery and one vein. It is associated with many major congenital anomalies and disorders (20% to 50% of fetuses).

Amniotic fluid volume: Abnormal volumes of amniotic fluid may suggest the fetus has a congenital anomaly.

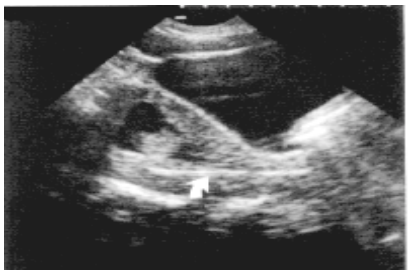
Polyhydramnios is typically associated with:

1. Central nervous system disorders
2. GI abnormalities

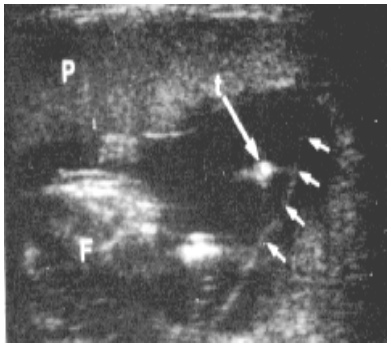
3. Hydrops
4. Skeletal anomalies

Oligohydramnios: is commonly associated with: DRIPP - Demise, Renal abnormalities, IUGR, Postdates (42 weeks), or Premature rupture of membranes (PROM)

Screening tests and genetic disorders:



Chorionic villus sampling: is an ultrasound directed biopsy of the placenta or chorionic villi, which obtains karyotype results similar to amniocentesis. Advantages over amniocentesis. It is performed early in pregnancy. Results are available within 1 week. Earlier results allow more options for parents. It can be performed transabdominally or endovaginally.



Amniocentesis: is a test performed by removing some of the amniotic fluid for analysis. The test can check for the following: Fetal lung maturity, RH Isoimmunization), alpha-fetoprotein levels, chromosomal abnormalities

Alpha-fetoprotein (AFP): is a major protein in the fetal serum and is produced by the yolk sac in early gestation and later by the fetal liver. It is found in the fetal spine, GI tract, liver, and kidneys. It is a screening test for neural tube defects and other conditions. AFP levels can be measured by 2 methods, maternal serum alpha-fetoprotein (MSAFP) and amniotic fluid alpha-fetoprotein (AFAFP). AFAFP– is measured from amniotic fluid. MSAFP is measured from the maternal serum. MFAFP detects 88% of anencephalics and 79% of open spina bifida cases. AFP levels are considered abnormal when they are low or elevated.

Common reasons for high AFP levels: Neural tube defects such as anencephaly and open spina bifida, renal anomalies, GI obstruction, chromosomal abnormalities, multiple gestation, incorrect dates.

Common reasons for low AFP levels: Chromosomal abnormalities, incorrect dates, fetal demise, hydatidiform mole, spontaneous abortion,

	Trisomy 21	Trisomy 18	Trisomy 13	Triploidy	Turner
Skull/brain					
Strawberry- head	–	+	–	–	–
Brachycephaly	+	+	+	–	+
Microcephaly	–	–	+	–	+
Ventriculomegaly	+	+	–	+	–
Holoprosencephaly	–	–	+	–	–
Choroid plexus cysts	+	+	–	–	–
Absent corpus callosum	–	+	–	–	–
Posterior fossa cyst	+	+	+	–	–
Large cisterna magna	+	+	+	–	–
Face/neck					
Facial cleft	–	+	+	–	–
Micrognathia	–	+	–	+	–
Nuchal edema	+	+	+	–	–
Cystic hygromata	–	–	–	–	+
Chest					
Diaphragmatic hernia	–	+	+	–	–
Cardiac abnormality	+	+	+	+	+
Abdomen					
Exomphalos	–	+	+	–	–
Duodenal atresia	+	–	–	–	–
Collapsed stomach	+	+	–	–	–
Mild hydronephrosis	+	+	+	–	+
Other renal abnormalities	+	+	+	+	–
Other					
Hydrops	+	–	–	–	+
Small for gest age	–	+	–	+	+
Relatively short femur	+	+	–	+	+
Clinodactyly	+	–	–	–	–
Overlapping fingers	–	+	–	–	–
Polydactyly	–	–	+	–	–
Syndactyly	–	–	–	+	–
Talipes	–	+	+	+	–

Medical genetics: Normal chromosomes – consist of 46 chromosomes, 22 pairs of autosomes and a pair of sex chromosomes.

Aneuploidy: is an abnormality of chromosome number.

Dominant disorder: is caused by too much or too little chromosome material. It is caused by a single defective gene (autosomal dominant). Usually inherited by one parent. An inherited dominant disorder carries a 50% chance that each time the pregnancy occurs, the fetus will have the condition.

Recessive disorder (autosomal recessive): is caused by a pair of defective genes, one inherited from each parent. The parents have a 25% chance of having a fetus with the disorder.

X-linked disorders: are inherited by boys from their mothers. Affected males do not transmit the disorder to their sons, but their daughters will be carriers for the disorder. The sons of female carriers have a 50% chance of being affected, and the daughters each have a 50% chance of being a carrier. An x-linked gene is located on the female sex chromosome and not the autosomes.

Chromosomal abnormalities: are found at birth in 1 of every 180 live births. They are associated in females of advanced maternal age. The advanced sonographer should be familiar with the physical features of more common chromosomal disorders. **Note:** Only a brief description of each abnormality will be given.

- **Trisomy 13** – results from an abnormal extra chromosome number 13.
- **Trisomy 18 (Edward's Syndrome) -** is one of the most common chromosomal abnormalities. The karyotype demonstrates an extra chromosome number 18.
- **Trisomy 21 (Down's Syndrome) -** is present in 1 of very 600 infants at birth. Caused by an extra chromosome number 21. It is associated with low alpha-fetoprotein levels.
- **Triploidy -** occurs when there is an extra set of chromosomes. It is often caused by the fertilization of two sperm.
- **Turner Syndrome (45,X) -** is a genetic abnormality marked by the absence of the x or y chromosome. Cystic hygroma is one of the most common pathogenic findings for this disorder.

If you notice any errors or typos in this study guide, please contact the Diagnostic Imaging CDC writer (currently MSgt Cheryl Vance) at DSN 736-3806 or e-mail cheryl.vance@sheppard.af.mil
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